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Sedimentary fill of basin wetlands, central Swan Coastal Plain, southwestern Australia. Part 2: distribution of sediment types and their stratigraphy

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Abstract

The composition of wetland sediments and the variation in wetland stratigraphy across and along the length of the Swan Coastal Plain are related to geologic/geomorphic setting, regional hydrochemistry, and climate. The east-to-west variation in sediments and stratigraphy is related mainly to geomorphic setting and hydrochemistry, as reflected in the consanguineous wetland suites on the Plain, and the south-north distribution is related to consanguineous suites and to climate. Specific sedimentary sequences reside in specific consanguineous suites: for example, autochthonous sediments in the Becher Suite in the Quindalup Dunes are dominated by calcilutite. Different wetland suites within the same geomorphic setting also exhibit different sedimentary sequences: for example, in the Spearwood Dunes autochthonous sediments in the Stakehill Suite are dominated by calcilutite and peat, those in the Coogee Suite are dominated by calcilutite, while those in the Yanchep Suite are dominated by peat, diatomaceous peat, and calcilutite. Autochthonous sediments in wetlands in the Bassendean Dunes are dominated by peat and diatomite. Basins on the Pinjarra Plain are filled with terrigenous sediment (kaolinitic mud, muddy sand, and sand) and peat.

Stratigraphy of wetland fills can be vertically simple, composed of one lithology, such as peat, calcilutite, or diatomite; or complex, composed of interlayered and mixed lithologies. For many wetlands, there also is a complexity in relation to the three-dimensional arrangement of facies, *viz.*, the central facies, the basal facies and the marginal facies, and asymmetry in sedimentary fill as a result of either facies changes, or variation in thickness in sediment accumulation across a basin, or variation in the depth of the original ancestral basin. Because of the variety of processes operating along wetlands margins, such as desiccation, bioturbation, pyrogenesis, amongst others, the marginal facies of wetland sedimentary fill is the most complex ensemble of sediment types in a given wetland basin.

Information on the distribution of wetland sediments, the range of sedimentary sequences occurring across the Swan Coastal Plain in relation to geomorphic setting and hydrochemistry, and the intrabasinal stratigraphic variation vertically and laterally within single basins provide important insights into wetland sedimentary evolution, and hence wetland evolution, and provide a physical and geochemical framework to understanding hydrologic functioning and ecosystem response.

Keywords: wetland sediments, wetland stratigraphy, wetland basin, Quaternary, Swan Coastal Plain

Introduction

The stratigraphic sequences under wetlands on the Swan Coastal Plain are archives in which are encoded geologic, hydrologic and hydrochemical history, vegetation and other biotic changes, and climate changes, as preserved in their sedimentary, diagenetic, floral and faunal records. These sequences, and their relationship to wetland margins, also underpin various hydrologic processes, providing information on how a wetland functions hydrologically, and providing a basis to interpret the vegetation distribution of wetlands with respect to edaphic and hydrologic features. In these contexts we stress that it is important to develop a stratigraphic framework as a prelude to palaeoenvironmental reconstructions of wetland development, to geohydrological investigations of wetlands, and to plant ecology studies.

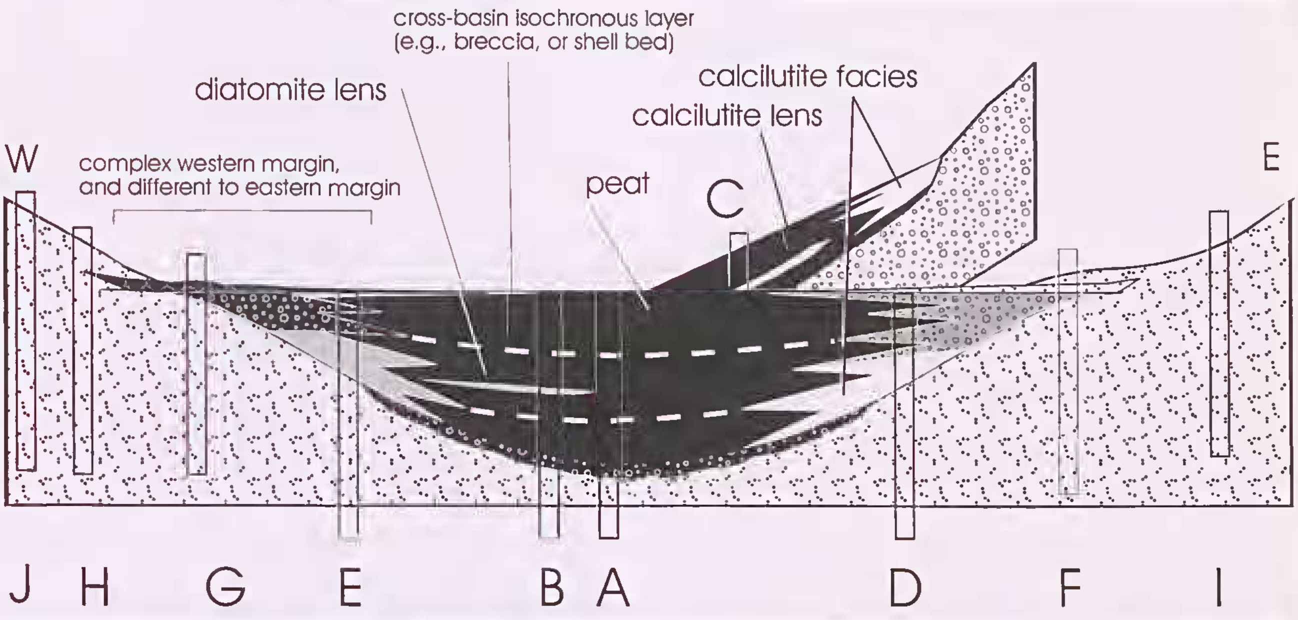
The importance of stratigraphy as a framework to the geohistoric, hydrologic, hydrochemical, and ecologic studies of wetlands was emphasised in a detailed study by C A Semeniuk (2006), using the young (< 4500 years) and relatively simple sedimentary sequences within wetland basins in the Becher Suite of the Quindalup Dunes. In the wetland basins of the Becher Suite there is a range of hydrological and hydrochemical responses to the geometry, thickness, composition and stratigraphy of the relatively simple basin fills, and hence response in the vegetation. Elsewhere on the Swan Coastal Plain, the sedimentary fill of wetland basins is older and more complex than those of the Becher Suite, and the wetlands contain a range of extant surface sediments and stratal types which vary according to geomorphic setting and regional host water chemistry (C A Semeniuk 1988), and so while the general stratigraphic principles exhibited by the wetlands of the Becher Suite are relevant to these latter wetlands, the details differ. Also, generally, wetlands outside the Becher Suite are larger and hence there is more scope for intrabasinal facies variation.

A number of authors have previously documented wetland sediments and their stratigraphic expression and thickness under the Swan Coastal Plain to varying degrees of detail. The distribution of wetland sediment types and their stratigraphy, in relationship to their setting within consanguineous wetland suites and within the geomorphic units of the Swan Coastal Plain, was presented at regional scale by C A Semeniuk (1988) in order to characterise the sedimentary and stratigraphic signature of those consanguineous suites. Locally, the stratigraphy of selected wetland basins on the Swan Coastal Plain was investigated as a framework for palynological studies and palaeoclimatic reconstructions (Newsome & Pickett 1993; Pickett 1998), though these types of studies tended to concentrate on a single core as representative of the history of a given wetland basin. Basin stratigraphy for some wetlands was presented by Allen (1980) and Hall (1985) who, in their studies of local hydrogeology of wetlands, provided generalised, lithologically simplified, cross-basin stratigraphy of the wetland sedimentary fills of Lake Jandabup and Lake Mariginiup, respectively, using a number of cross-basin sampling sites to provide information on the geometric form of wetland basin fill. Megirian (1982) and C A Semeniuk (2006), to date, have provided the most detailed studies of the stratigraphy of wetland basins on the Swan Coastal Plain. Megirian (1982) studied cross-basin stratigraphy of the Bibra Lake to North Lake wetland chain in some detail, providing cross-basin information and down-profile lithologic variation to reconstruct palaeo-sedimentology. C A Semeniuk (2006) studied some 16 wetland basins in the Becher Suite, as noted above, similarly providing cross-basin information and down-profile lithologic variation to reconstruct palaeo-sedimentology, and to relate hydrology, hydrochemistry, vegetation associations, and palynology to the stratigraphic system.

While the use of a single core within a wetland basin can provide information on palaeobiological sequences with a view to unravelling biological history as a surrogate for climatic, hydrological and hydrochemical history, this approach does not address the whole-of-basin stratigraphy of wetlands, which includes wetland margin sedimentologic and hydrologic effects, basinal and marginal hydrochemistry, and cross-basin variation in biota and sedimentation patterns (Fig. 1). Given the complexity that may be present stratigraphically across a basin, and down the stratigraphic profile, researchers using information derived from a single core within a wetland to reconstruct palaeobiological sequences need to address the problem that lithological and palaeobiological changes within a given core may be representing across-basin extensions of marginal facies and biota. To fully investigate wetland stratigraphy, and to rigorously interpret the stratigraphic sequences in terms of sedimentology, palaeobiology, palaeoclimate, and palaeohydrochemistry, firstly, it is necessary to have developed a series of wetland stratigraphic standards that can be related to their geologic, geomorphic and hydrochemical setting, and secondly, to have constructed across-basin stratigraphic relationships. Such stratigraphic information then would provide a basis on which to separate interbasin lithological variation from intrabasin variation within the same consanguineous suites, and interbasin variation between different consanguineous suites. Vertical lithologic variation in wetland stratigraphy, and its possible associated biostratigraphy, from single cores then could be more confidently assigned to one of the following: 1. intrabasin facies variation (reflecting Walther's Law; Walther 1894; Middleton 1973); 2. intrabasin factors such as hydrochemical and ecological evolution within the wetland; or 3. intrabasin lithologic (whole-of-basin) changes driven, for instance, by regional factors such as climate changes, or regional hydrochemical changes. Interbasin stratigraphic changes within and between consanguineous suites also then could be more confidently assigned to variations reflecting hydrochemical setting.

Relating surface sediment types and sedimentary fill within wetland basins to geomorphic setting and extant hydrochemistry and extant biota is the primary step in understanding the distribution of lithologic sequence(s) geographically, and should precede interpretation of stratigraphic sequences in terms of their palaeo-hydrochemical setting and palaeo-environmental setting. Further, documenting variation of interbasin wetland stratigraphy in relation to geomorphic setting ideally should form the foundation to untangling the hydrological, hydrochemical, ecological, and climatic factors that underpin stratigraphic evolution. Such an approach would place palaeobiological sequences and single-core lithological sequences for large wetland basins into a palaeo-environmental, intrabasinal, and interbasinal context.

To date, however, apart from the regional work of C A Semeniuk (1988), the distribution of wetland basin sediment types across the Swan Coastal Plain and the stratigraphic sequences within the wetlands have not been subject to a systematic and comprehensive description, and the details of their sedimentary fill remain largely unexplored. This paper is the second in a series on the sediments and sedimentary fill in wetlands across the central Swan Coastal Plain. It reports on the variety of stratigraphic sequences in basin wetlands that occur across the length and breadth of the Swan Coastal Plain, extending the detailed stratigraphic work of C A Semeniuk (2006) in wetland basins of the Becher Suite. However, as a prerequisite to describing the types and distribution of stratigraphic sequences, we describe sediment types that occur within wetland basins in relation to geomorphic setting and geographic (and hence climatic) setting. As such, this paper describes the distribution of surface sediment types in wetland basins across the central Swan Coastal Plain, and from there describes the standard stratal types within wetlands, the range of across-basin stratigraphic relationships, and the wetland basin stratigraphic diversity and internal variability. Full interpretation of the results of the stratigraphy of the wetlands presented in this paper, however, in terms of basin-specific sedimentary history, Fence diagram, with sections oriented E-W and NE-SW, of an idealised basin with complex sedimentary fill, internal facies changes, complex margins, evidence of wetland contraction, and asymmetry in stratigraphy



A single core at site A in the central basin: provides a simple stratigraphic sequence, and potentially an erroneously simple reconstruction of wetland history

A single core at either site A, B or C in the central basin: provides different stratigraphic sequences, and different reconstructions of wetland history

Multiple cores at sites A, B & C in the central basin: provide a more complex stratigraphic picture of intrabasinal facies changes, with documentation of intrabasinal facies changes across time and space, and more realistic reconstruction of a complex wetland history

Cores at sites D & E, in addition to those in the central basin: provide complex stratigraphic picture of intrabasinal facies changes across time and space, and variations in the marginal facies in response to fluctuations of hydrology,hydrochemistry, and biota, and hence a more complex and complete reconstruction of wetland history

The full suite of cores A to J, from central basin to upland: provides a complex stratigraphic picture of wetland facies, a context for upland-to-wetland interactions in terms of source materials, tongues and lenses of sand extending into the wetland, and a more complete picture of extant functioning and the history of the wetland in relation to hydrology, hydrochemistry, and biota; it may also help define the limit of the proto-wetland, or former wetland (from core H).

Figure 1. Cross-section of an idealised wetland showing an internally complex sedimentary fill with the various stratigraphic sequences that can be derived from single cores *versus* multiple cores. Multiple cores in transects across such basins, with focus on the wetland margins (where the process of drying and wetting is most frequent, and where the response to changes in climate, hydrology, or hydrochemistry is most marked), are the best way to unravel the wetland sedimentary history, and to relate the complex sedimentary response to wetland history in response to a changing climate, or a changing hydrochemistry.

hydrologic history, hydrochemical history, fire history, and climate changes, is beyond the scope of this paper, and will be presented in a later paper where the stratigraphic sequences are integrated with radiometric ages (Semeniuk & Semeniuk 2006, unpublished manuscript).

The geographic and environmental scope of this paper encompasses selected individual wetland basins between Gingin Brook and Bunbury. It includes wetland basins within the Quindalup Dunes in the Rockingham area (C A Semeniuk 2006), the Spearwood Dunes, Bassendean Dunes and local parts of the Pinjarra Plain (Fig. 2), but

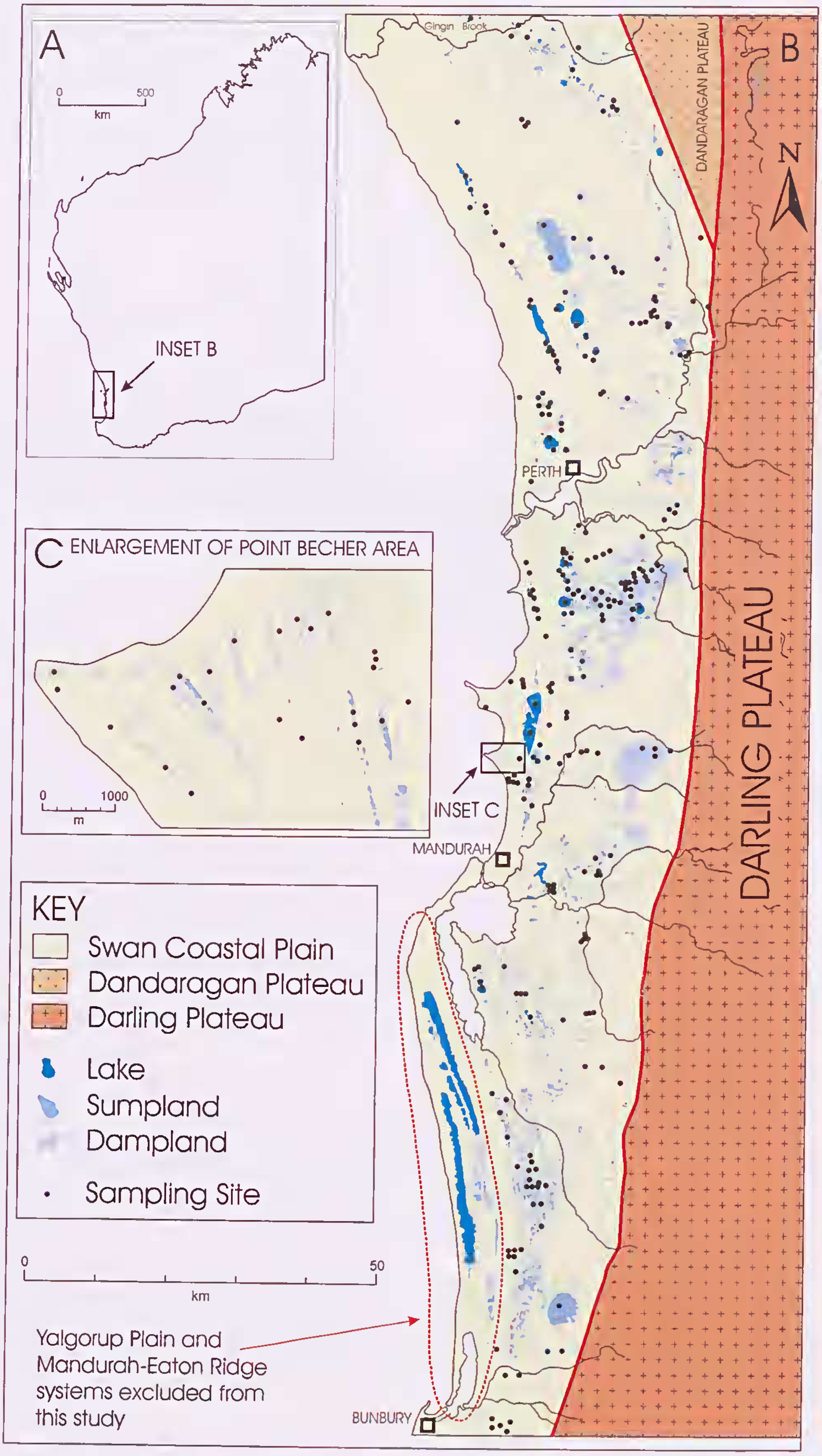


Figure 2. Location of wetlands and study sites within the central Swan Coastal Plain between Gingin Brook and Bunbury. Inset C shows details of the location of selected study sites in the Point Becher area (more detailed maps showing the comprehensive sampling locations in the Point Becher area are shown in C A Semeniuk 2006). The mapping of wetland basins as lakes, sumplands, and damplands was undertaken between 1990 and 1996 by the V & C Semeniuk Research Group, and the GIS data set is held by the former Water & Rivers Commission (now the Department of Environment and Conservation).

excludes wetlands on the Yalgorup Plain and the Mandurah-Eaton Ridge (Semeniuk 1995) which are the subject of a separate study.

The wetland classification of C A Semeniuk (1987) is used in this paper. As this paper concentrates only on basin wetlands, the relevant terms are lake (= permanently inundated basin), sumpland (= seasonally inundated basin), and dampland (= seasonally waterlogged basin). The issues of the term wetland "soil" as distinct from terms such as wetland "sediments", "stratigraphy", "stratigraphic sequence" and "sedimentary fill" have been dealt with in Semeniuk & Semeniuk (2004). In this paper, following Semeniuk & Semeniuk (2004), wetland sediments are primary infiltrational and accretionary deposits within wetland basins, and the sedimentary fill therein forms stratigraphic sequences, and thus the term "soil" is not applied to them. The boundary of a wetland basin for a lake will encompass (from wetland centre to periphery) zones of permanent inundation, seasonal inundation, and seasonal waterlogging, for a sumpland, zones of seasonal inundation, and seasonal waterlogging, and for a dampland a single zone of seasonal waterlogging. Hence, these various wetland zones are underlain by a range of infiltrational and accretionary wetland sediment deposits formed under conditions of permanent inundation, or seasonal inundation, or seasonal waterlogging (Fig. 3).

The terms for wetland sediment types follows Semeniuk & Semeniuk (2004). The term "basement" in this paper (following Semeniuk & Semeniuk 2004) refers to the floor of the ancestral wetland basin, which may be composed of Pleistocene quartz sand, Pleistocene limestone, or Holocene dune or fluvial sediments.

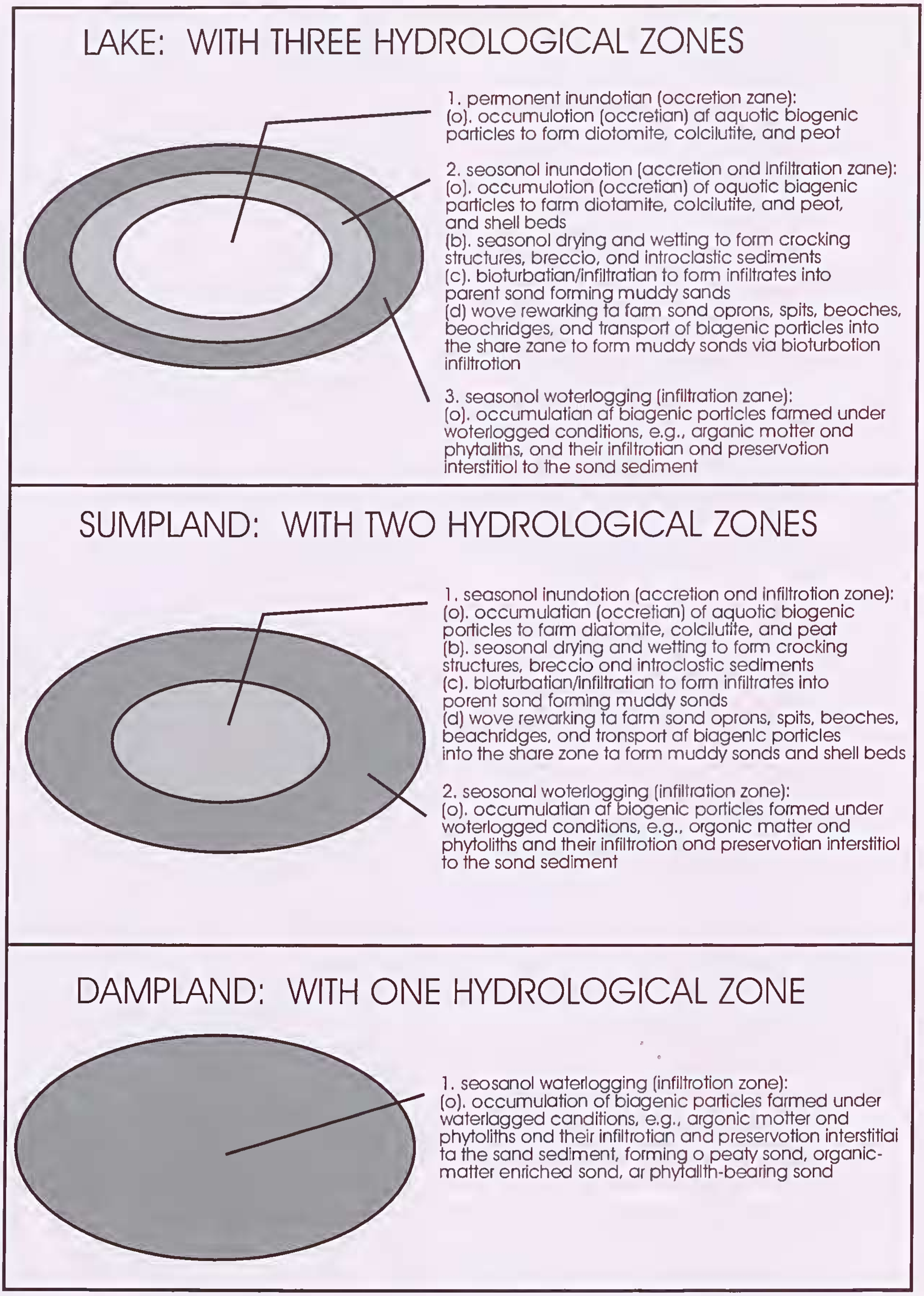
Sites, materials and methods

Over 250 wetland basins have been studied sedimentologically and stratigraphically for this paper (Figures 2 and 4). These include the 143 wetlands studied by Semeniuk & Semeniuk (2004), the 23 wetlands in the Becher Suite described by C A Semeniuk (2006), and some 85 additional wetlands surveyed as part of a wider regional study of freshwater sponges on the Swan Coastal Plain. Figure 2 shows the extensive occurrence of lakes, sumplands and damplands on the Swan Coastal Plain, as mapped by the V & C Semeniuk Research Group between 1990 and 1996, and the extent of sediment sampling undertaken. Not all wetlands have been sampled sedimentologically, but the sampling has covered a representative proportion of the wetland basins across the breadth and length of the Swan Coastal Plain between Gingin Brook and Bunbury, and within the various geomorphic units. In comparing the distribution of basins with respect to geomorphic setting (Figures 2, 4 and 5), note that there is a dearth of basins in the Pinjarra Plain. Most wetland basins are located in the Bassendean Dunes. However, to provide a balanced comparison of sedimentary patterns across the geomorphic units, effort was made to locate and sample a reasonable number of basins on the Pinjarra Plain. Across the whole of the study area the selection of sampling sites was based on spacing of wetlands, and accessibility.

At each sampling site, sediment samples were collected from the centre and margins of the wetlands at depths of 0–5 cm and at 20–30 cm, to characterise their surface and shallow depth sediment types. Stratigraphy of wetlands was determined along transects by examination of dewatered trenches and excavations (to 4 m) in 17 wetlands, and shallow augering in 70 wetlands (with the depth of augering, from 1 m to 5 m depth, depending on the thickness of the sedimentary fill). Additionally, in 35 of the wetlands, reverse-air-circulation coring to 30 m was undertaken (see map of locations in C A Semeniuk 1988). Augering/coring to several metres below the base of the wetland sedimentary fill into the basement sand, or limestone, and coring to depths of 30 m were undertaken to ensure that the full sequence of Holocene and any Pleistocene sedimentary fill was recorded, and to ensure that any Pleistocene wetland sequences (if present) developed *under* late Pleistocene sand sheets were intersected (*i.e.*, if indeed such sand sheets are present, separating Pleistocene and Holocene sequences).

Cliff faces provided by dewatered trenches and excavations allowed direct observation and description of wetland stratigraphy, sedimentary and biogenic structures, and sediment types. Artificial exposures were described in 12 un-named wetland basins at Osborne Park, Bullcreek, and Forrestdale, as well as in excavation trenches in Lake Gwelup, Little Carine Swamp, Lake Pinjar, and Karrinyup Road Swamp. Short cores of *in situ* sediment were obtained from a range of wetlands to study surface and near-surface sedimentary structures and micro-structures. These short cores were obtained by pushing 10 cm diameter PVC pipes, 10–30 cm long, into the substrate, retrieving them, and processing them in the laboratory. At some 46 sites, 75–100 cm long cores also were obtained, and for 6 sites with relatively deep stratigraphic sequences, cores to 5 m were obtained. In the laboratory, these cores, generally in a water-saturated state, or at least with pellicular water still present, were frozen for storage and ice-hardening. The cores later were longitudinally sliced while frozen to cleanly expose the lithology, stratigraphy, and sedimentary structures. One half was returned to frozen storage as archive material; the other half was photographed, and used in further analyses. At each wetland study site, topographic profiles and stratigraphy along transects were established by survey. Stratigraphic and topographic transects traversed adjoining upland through to wetland environments. Topographic levelling facilitated correlation of stratigraphic units within wetlands and the placement of the sedimentary fill in relation to the Australian Height Datum (AHD) for use in a later paper.

Sediments were described from cores, trenches and other excavations in terms of colour, structure, fabric, texture, and composition with stereoscopic microscope. Auger samples were similarly described, but with the omission of sedimentary structure. In the laboratory, samples returned were mounted on slides and studied by stereoscopic microscope and petrographic microscope as described by Semeniuk & Semeniuk (2004). Details of the laboratory analyses of sediments have been presented in Semeniuk & Semeniuk (2004).



LAKE: WITH THREE HYDROLOGICAL ZONES

1. permanent inundation (accretion zone):
(a). accumulation (accretion) of aquatic biogenic particles to form diatomite, calcilutite, and peat

2. seasonal inundation (accretion and infiltration zone):
(a). accumulation (accretion) of aquatic biogenic particles to form diatomite, calcilutite, and peat, and shell beds
(b). seasonal drying and wetting to form cracking structures, breccia, and intraclastic sediments
(c). bioturbation/infiltration to form infiltrates into parent sand forming muddy sands
(d) wave reworking to form sand aprons, spits, beaches, beachridges, and transport of biogenic particles into the shore zone to form muddy sands via bioturbation infiltration

3. seasonal waterlogging (infiltration zone):
(a). accumulation of biogenic particles formed under waterlogged conditions, e.g., organic matter and phytoliths, and their infiltration and preservation interstitial to the sand sediment

SUMPLAND: WITH TWO HYDROLOGICAL ZONES

1. seasonal inundation (accretion and infiltration zone):
(a). accumulation (accretion) of aquatic biogenic particles to form diatomite, calcilutite, and peat
(b). seasonal drying and wetting to form cracking structures, breccia and intraclastic sediments
(c). bioturbation/infiltration to form infiltrates into parent sand forming muddy sands
(d) wave reworking to form sand aprons, spits, beaches, beachridges, and transport of biogenic particles into the shore zone to form muddy sands and shell beds

2. seasonal waterlogging (infiltration zone):
(a). accumulation of biogenic particles formed under waterlogged conditions, e.g., organic matter and phytoliths and their infiltration and preservation interstitial to the sand sediment

DAMPLAND: WITH ONE HYDROLOGICAL ZONE

1. seasonal waterlogging (infiltration zone):
(a). accumulation of biogenic particles formed under waterlogged conditions, e.g., organic matter and phytoliths and their infiltration and preservation interstitial to the sand sediment, forming a peaty sand, organic-matter enriched sand, or phytolith-bearing sand

Figure 3. The broad sedimentary setting of the various zones of a wetland basin (as a lake, sumpland, or dampland) in relation to permanent inundation, seasonal inundation, seasonal waterlogging, and the simplified outline of the types of sediments accumulating in terms of lithology and their status as infiltrational or accretionary deposits. This diagram focuses on intrabasinally generated biogenic sediments rather extrabasinal sediments. Muddy sand in this diagram refers to peaty sand, calcilutaceous muddy sand, or diatomaceous muddy sand (see Semeniuk & Semeniuk 2004).

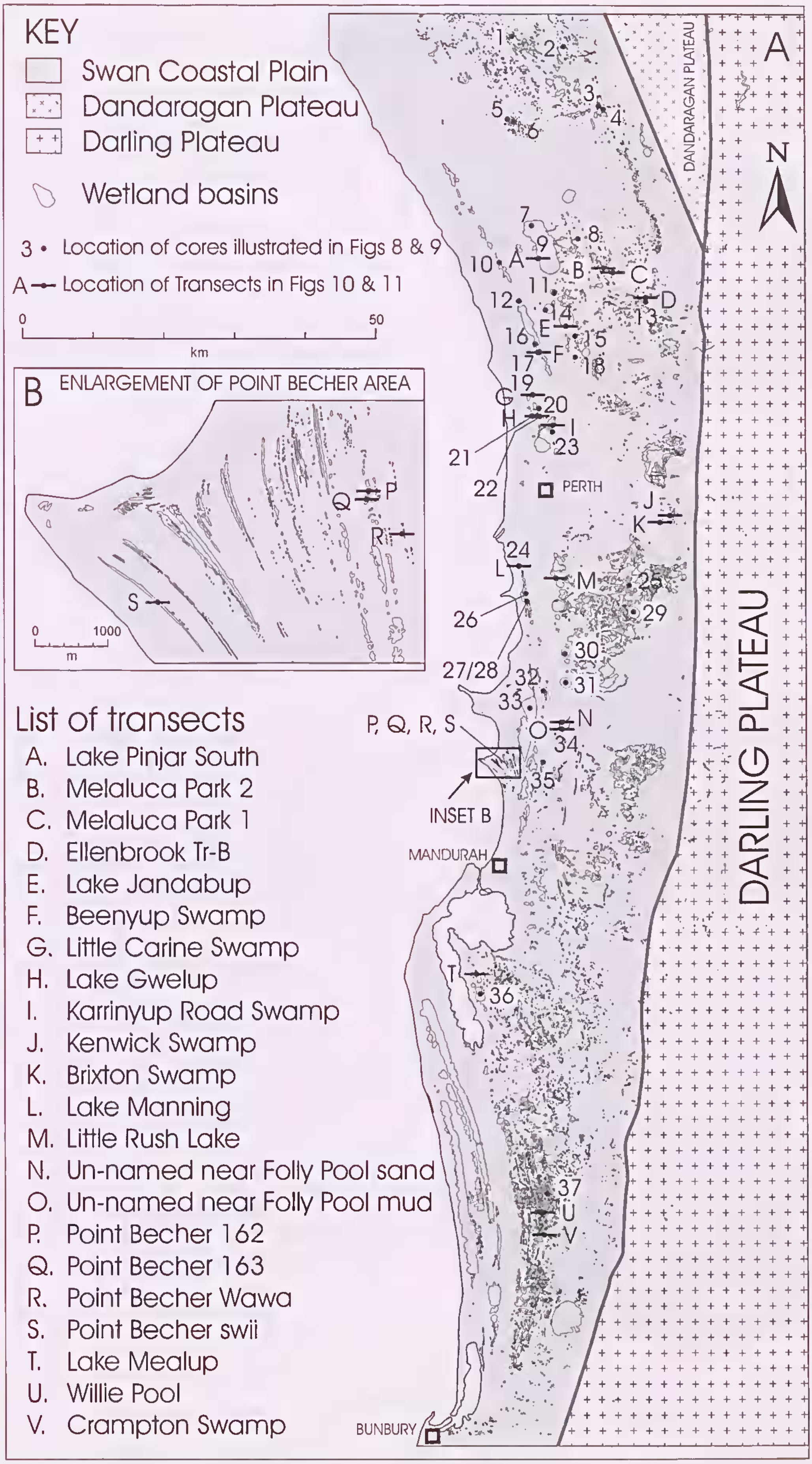


Figure 4. Study sites where data are used in the illustrations of cores and transects in this paper.

Wetlands on the Swan Coastal Plain and their geologic, geomorphic, hydrochemical, and consanguineous setting

Geologic and geomorphic setting

The Swan Coastal Plain, which is host to a variety of wetlands, is the Quaternary surface of the Perth Basin (Playford *et al.*, 1976), and comprises distinct large-scale landforms largely arranged subparallel to the Darling Scarp, or subparallel to the coast, or are associated with major rivers. These landforms correspond to the main Quaternary sedimentary formations in the region (Woolnough 1920; McArthur & Bettenay 1960; Playford *et al.*, 1976; McArthur & Bartle 1980a,b; C A Semeniuk 1988; Semeniuk & Glassford 1987, 1989; Semeniuk *et al.*, 1989; Geological Survey of Western Australia 1990; Semeniuk 1995). The main units from east to west are (Fig. 5):

- Pinjarra Plain: flat to gently undulating alluvial fans fronting the Darling Scarp and Darling Plateau (underlain by sand, laterite, and Precambrian rocks), as well as floodplains and various sized channels; underlain by the Guildford Formation (clay, laterite, sand, muddy sand);
- Bassendean Dunes: undulating terrain mostly of low degraded dunes (varying in relative relief from 20 m to almost flat), and interdune flats and basins; underlain by the Bassendean Sand (quartz sand) of Pleistocene age;
- Spearwood Dunes and Yalgorup Plain: large-scale, linear, near-continuous subparallel ridges (up to *circa* 60 m relief) and intervening narrow and steep-sided depressions, or of narrow plains; underlain by Pleistocene limestone (aeolianite and marine limestone) blanketed by quartz sand; and
- Quindalup Dunes: Holocene coastal dunes, beach ridge plains, tombolos and cuspate forelands; underlain by quartzo-calcareous sand.

In the southern part of the study area, there is the Yalgorup Plain (underlain by limestone and quartz sand, and equivalent to the Spearwood Dunes), which is separated from the Bassendean Dunes by the Mandurah-Eaton Ridge, a ridge of moderate relief underlain by quartz sand (Semeniuk 1995; and Figures 2 and 5).

In these settings, there are four main lithologic/stratigraphic units that either adjoin or underlie wetlands: 1. Pleistocene yellow to white quartz sand; 2. Pleistocene limestone; 3. Holocene quartzo-calcareous sand; and 4. Pleistocene to Holocene fluvial sand, muddy sand, and mud.

The array of sampling sites for this study, within the framework of the geomorphic units to illustrate the extensive sampling along the length and breadth of the Swan Coastal Plain in relation to these geomorphic units, is shown in Figure 5.

Hydrochemical setting

Most of the Swan Coastal Plain is underlain by an unconfined groundwater body that resides in a variety of aquifers, which are variable in lithology, depending on geological setting. The aquifers include quartzo-calcareous sand, calcareous sand, limestone, interlayered limestone and quartz sand, quartz sand, muddy sand, and interlayered sand, muddy sand and mud, corresponding to the formations of Safety Bay Sand, Becher Sand, Tamala Limestone and other "coastal limestones", Bassendean Sand, and Guildford Formation (Playford *et al* 1976, Semeniuk & Searle 1985; Semeniuk 1995).

Groundwater is mostly fresh, with salinities ranging from < 250 ppm to 1000 ppm, though locally there are tongues and lenses of groundwater with salinity 1000–2000 ppm and limited occurrences with salinity > 2000 ppm (Davidson 1995).

The hydrochemistry of the groundwater will have an influence on wetlands in its effect on biota, and its effect on sediments and diagenesis, and thus in this context it is important to develop a framework of hydrochemistry within which to deal with wetland sedimentation and stratigraphy. Table 1 summarises the hydrochemistry of the Swan Coastal Plain in relation to landscape setting with respect to salinity, pH, and Ca, Si, and Fe content. These data are not chemical parameters of waters in wetlands themselves but of the groundwater of the terrain in which wetlands may reside. Groundwater pH, where alkaline, provides an indication of how much $CaCO_3$ has been dissolved from the aquifer lithology; acidic waters signal waters residing in aquifers of low carbonate content. The quartz sands of the Swan Coastal Plain often are Fe-stained, with coatings of Fe oxides (as yellow goethite and red haematite), and Fe pigmentation of the clay and silt coating around the quartz grains, resulting in yellow colouration of the sand in the region (Glassford 1980; Semeniuk & Glassford 1989; Glassford & Semeniuk 1990). Acidic waters disaggregate the coatings and mobilise this Fe into solution (Semeniuk &

Table 1

Summary of selected telluric hydrochemistry of groundwater of the Quindalup Dunes, Spearwood Dunes, and Bassendean Dunes

Geological/geomorphic setting	Salinity (ppm) mean (& range)	pH mean (& range)	Ca (ppm)	SiO_2 (ppm)	Fe (ppm)	No of samples
Safety Bay Sand (Quindalup Dunes)	446 (300–1100)	7.9 (6.8–8.8)	32	15	0.2	110
Tamala Limestone (Spearwood Dunes)	420 (290–900)	6.3 (6.1–7.2)	53	14	0.5	96
Bassendean Sand (Bassendean Dunes)	340 (70–1750)	5.5 (4.3–7.0)	9	11	0.7	144

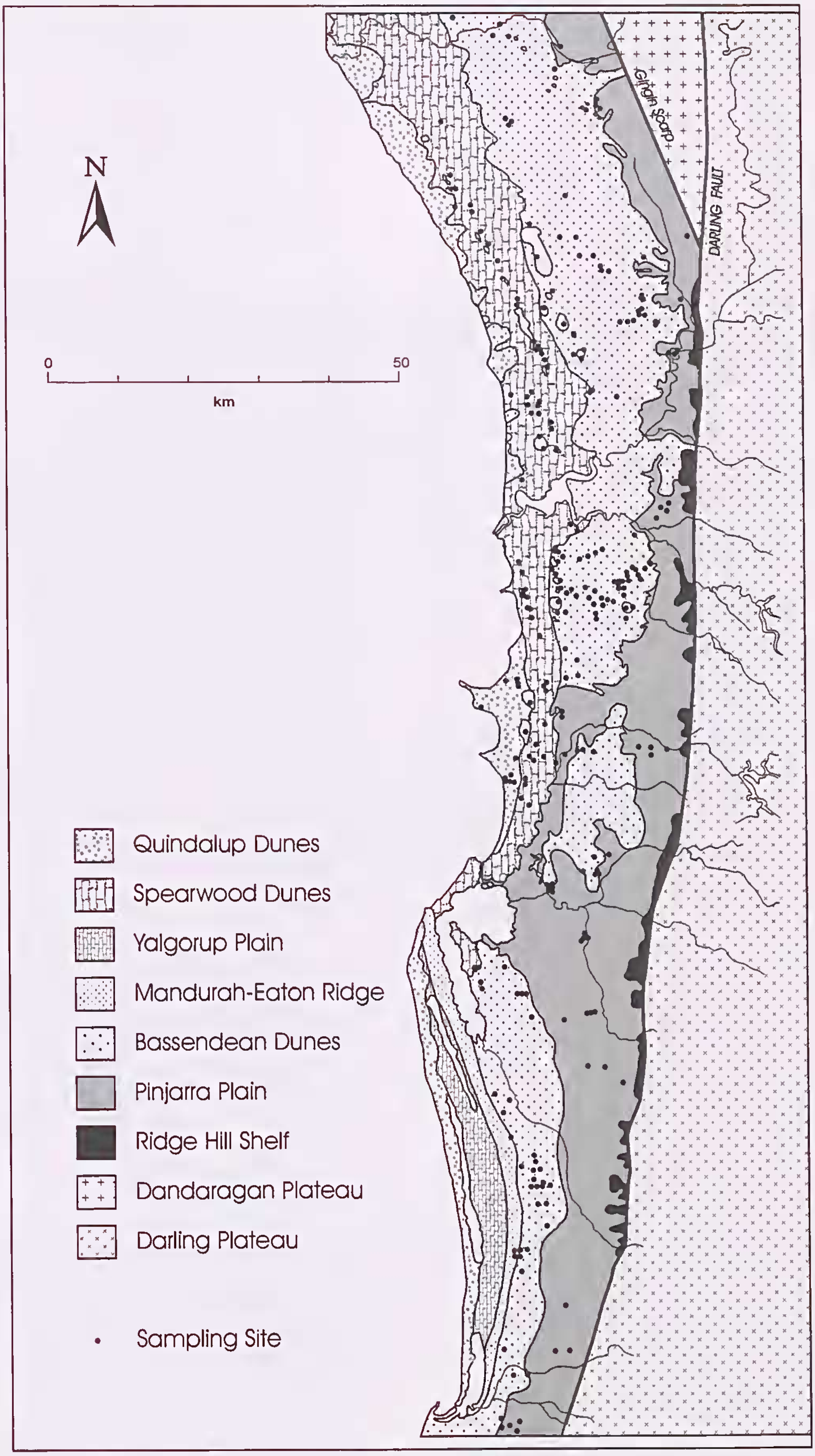


Figure 5. The geomorphic framework of the central Swan Coastal Plain (modified after McArthur & Bettenay 1960, with information on the Yalgorup Plain and Mandurah-Eaton Ridge from Semeniuk 1995) with overlay of location of study sites to illustrate extensive sampling in relation to the various geomorphic units.

Semeniuk 2004), such that groundwaters that are slightly acidic and in contact with yellow sand will have higher Fe content, and alkaline waters will have relatively lower Fe content. Similarly, alkaline waters are silica dissolving, and acidic waters are silica precipitating, hence the pH of groundwater will relate to the content of silica in solution (Correns 1950; Krauskopf 1956; Okamoto *et al.* 1957). There is more SiO_2 in solution in groundwaters of carbonate terrains with alkaline water than in terrains of quartz sand with acidic waters, as alkaline waters favour the solution of silica, even though the content of silica (as sand grains) is higher in the latter terrains. The Ca content is a measure of how much calcareous material has been dissolved from host rocks and carbonate-bearing sands into the groundwater, and thus is a measure of the telluric nature of the groundwater. Consequently, the Ca, Fe, and Si content of groundwater can be used as a measure of its telluric nature, and a measure of how much the lithology of the aquifers determines the chemical nature of ground waters before they have reached wetlands.

These water quality parameters show that source waters that will enter wetlands are generally of low salinity. If they are telluric in character deriving from calcareous hosts they will have relatively elevated Ca content, and neutral to alkaline pH. If they are deriving from quartz rich terrains they will be acidic, and with relatively low Ca content.

In contrast, rainwater data presented by C A Semeniuk (2006) on the Quindalup Dunes in the Becher Point area, collected over a number of years, show its salinity is 99 + 116 ppm 0.5 km from the coast, and 114 + 86 3–4 km from the coast. Its Ca content is as low as 6.6 ppm and ranges up to 9.5 ppm, equivalent to the Ca content of groundwater in the Bassendean Sand. Its Fe content is 0.03 ppm, and SiO_2 content is 1.24 ppm. Data from 80 samples collected daily at Floreat over 1996–1998 (Rich & Semeniuk, unpublished MS) show the salinity of rainwater to be 299 + 227 ppm (range 30 ppm – 980 ppm), its Ca content to be 1.6 + 1.5 ppm, and its Fe content to be 0.02 + 0.02 ppm.

The low cation and SiO_2 content of rainwater in contrast to the higher Ca, Fe and content of groundwaters (correlative with the various aquifer settings) show the effect of aquifer geochemistry on the hydrochemistry of telluric waters.

Hingston & Gailitis (1976) provide data on the salt content of rain water in the southwest of Western Australia, with study sites relevant to this paper at Yanchep, Floreat, Perth, Harvey, and Bunbury. Their results, however, are not directly comparable to those of this paper mainly because they have converted salt content (whether total salt, Cl, or specific cations) to values of kg/ha.

Some of the important aspects of hyrochemistry in relation to wetlands, particularly in their influence on biota, sediments and diagenesis, are: 1. salinity (which effects selection, elimination, and productivity of biota, and hence generation of biogenic sedimentary particles); 2. the Ca-and-HCO_3 content (which firstly effects the availability of Ca and HCO_3 ions and hence the rate of acquisition of carbonate minerals by biota, and secondly, influences diagenesis); 3. Si content (which influences diatom occurrence); 4. pH (which influences biota, long term residency time of annually generated fine-grained carbonate particles and fine-grained biogenic silica particles, and Fe hydrochemistry and geochemistry); and 5. water colour (*e.g.*, tannin content, which influences benthic and planktonic biota, and which may also regulate other aspects of water chemistry and microbiota). Components such as NO_3 and PO_4 also were important aspects of hydrochemistry in their influence on the productivity of biota and hence generation of sedimentary particles, but it is now difficult to assess the importance of these chemical species in determining distribution of sediment types because there has been major anthropogenic nutrient enrichment of wetlands from urbanisation and agricultural development, which has confounded any original patterns.

Meteoric waters, derived from oceanic air masses and containing salt spray, essentially mirror the chemistry of diluted seawater, and hence largely reflect its cationic ratios, while water originally derived from meteoric sources residing for some time in chemically distinct aquifers carries the signature of those aquifers as telluric waters (Table 1). Waters residing in wetlands, regardless of whether they derive from meteoric sources, or initially carry telluric signatures, commonly reflect the processes that operate in wetlands. For example, wetlands with perched meteoric water (and where there is little vertical throughflow such that evaporation is dominant over meteoric input and groundwater throughflow) tend to contain brackish to saline water. Wetlands underlain by carbonate sediments have waters enriched in Ca ions, as the surface waters chemically equilibrate with the sediments (*cf.* C A Semeniuk 2006). Wetlands underlain by peat tend to have tannin-stained, acidic waters, and wetlands underlain by diatomite (usually with organic matter enriched surface layers) also tend to have tannin-stained, acidic waters.

Phreatic waters under wetlands, below the zone of water table fluctuation, have a variable hydrochemistry, as determined by the geochemistry of each wetland sedimentary fill, and the complexity of the lithological layering in wetland sedimentary sequences (C A Semeniuk 2006). The hydrochemistry of downward percolating groundwaters has little influence on sediment generation within wetlands but would have an effect on shallow-depth wetland sediment diagenesis. For wetlands partially maintained by local artesian or subartesian water, the chemical perturbations and chemical signature effected by subsurface wetland sediments have some influence in determining wetland surface water chemistry.

To deal with the complexities of the chemical variation and evolution of surface and groundwater within and around wetlands, as discussed above, the hydrochemistry of waters within wetlands and groundwater under the Swan Coastal Plain in relationship to wetlands is categorised, in this paper, into three spatial fields relative to a wetland basin:

> Type 1: groundwater *within* the geological/geomorphic setting where the wetland resides; this potentially reflects the hydrochemistry of the source waters for the wetlands (where local artesian and subartesian waters are not involved), and will be one

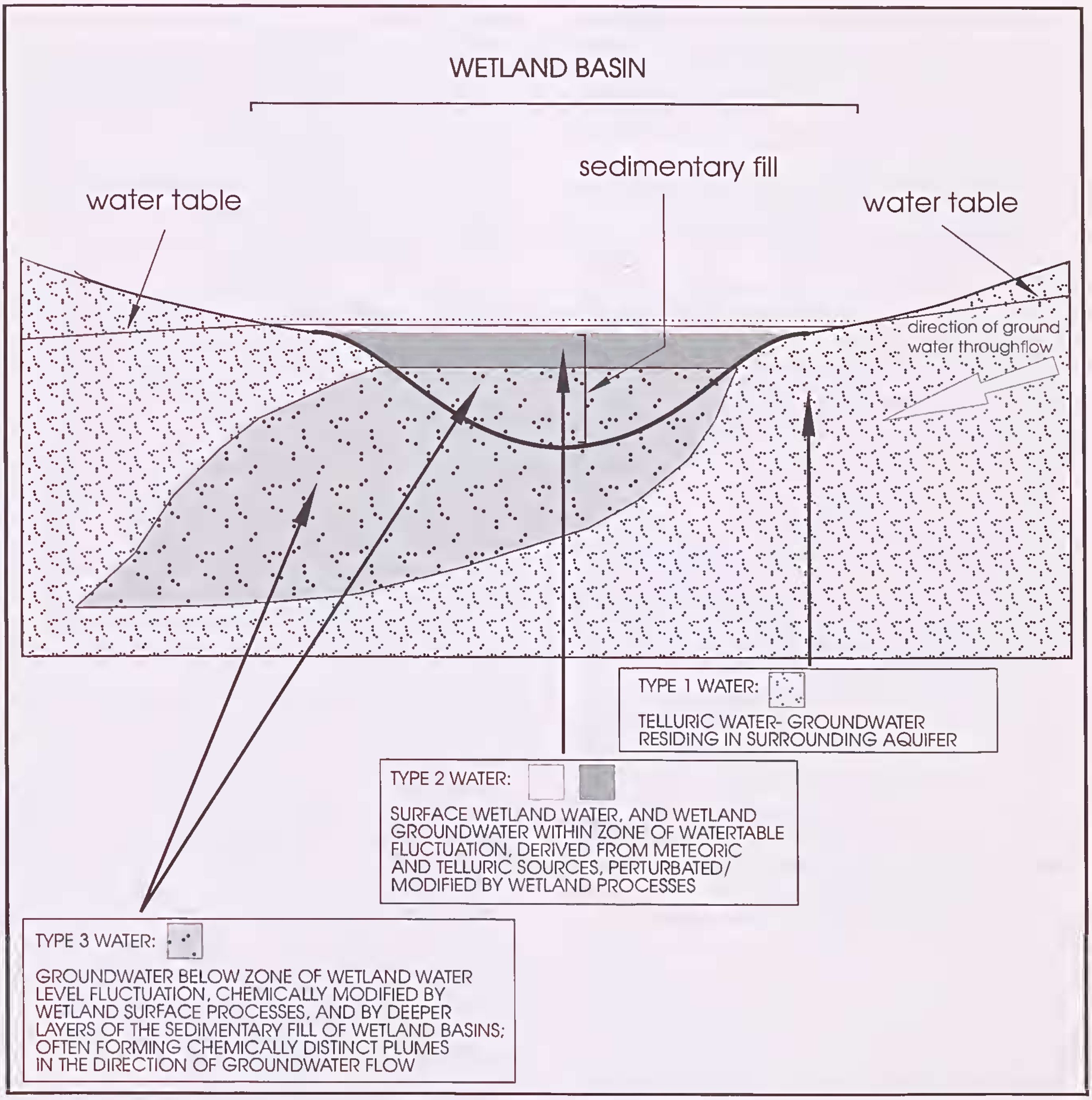


Figure 6. Simplified distribution of hydrochemical patterns of groundwater in and around wetlands.

of the fundamental determinants of the biogenic sediment types generated in wetland basins;

Type 2: surface water and shallow groundwater *within* the wetland; this reflects the chemistry of the source waters (such as direct meteoric input, groundwater throughflow, input of surface water run-off, and artesian/subartesian upwelling), with the overprint of chemical perturbations effected by surface and near-surface processes within the wetlands; and

Type 3: phreatic water residing in wetland sediments and basement materials *under* the wetland surface below the zone of water table fluctuation; this reflects the chemistry of the source waters, descending plumes of hydrochemically distinct water derived from surface and near-surface of the wetland (and thus the product of biological, chemical, and physical processes at the surface and near-surface of the wetland), and the hydrochemical equilibrium effected on water chemistry by diagenetic processes in the phreatic zone under wetlands; while it may affect the geomorphic and hydrologic evolution of wetlands (e.g., causing dissolution and subsidence in calcareous sediment hosted wetlands, *cf.* C A Semeniuk 2006, or creating relatively impervious layers through diagenetic precipitation of minerals in the subsurface), this water will have little direct effect on the development of sediments on the wetland surface.

The types of water bodies within and around wetlands, their origin, and their generalised hydrochemical signature, are illustrated in Figure 6. This illustration does not address direct meteoric input, which itself, once it enters the wetland, will be modified to a Type 2 water category.

The notion of hydrochemical modification of groundwater by, for example, anoxic wetland sediment, resulting in hydrochemically distinct zones hydrologically up-catchment and down-catchment of wetlands (essentially the water Type 1 *versus* waters Types 2 and 3 of this study) was suggested by Stuyfzand & Moberts (1987) for flow-through lakes in wetlands (dune slacks) in The Netherlands, as a result of using various chemical species such as potassium, nitrate, sulphate, bicarbonate ions, and dissolved organic carbon as tracers to detect hydrochemically distinct plumes. These hydrochemically modified waters also resulted in subsurface sediment modification. For instance, diagenetic zones, with sediment depleted of carbonate in response to the hydrochemically distinct plumes descending down-flow from a wetland, were identified under dune slacks in The Netherlands by Grootjan *et al* (1996) and Sival & Grootjan (1996).

On the Swan Coastal Plain, phreatic water modified by wetland processes (Type 3 water) has been detected as plumes descending from wetland basins by Allen (1980), Hall (1985), and C A Semeniuk (2006). Similar plumes of wetland-modified water are described in the models presented by Townley *et al.* (1993) for Jandabup Lake, Thomson Lake, and Nowergup Lake, using Deuterium and Chloride tracers. They identify the outflow zones around lakes as the "release zone". C A Semeniuk (2006) detected diagenetic zones of carbonate dissolution (carbonate depletion) down-flow of a groundwater through-flow system in response to geochemical plumes (equivalent to Type 3 water) under wetlands in the Point Becher area.

Consanguineous wetland setting

A wide range of basin wetland types occurs on the Swan Coastal Plain, varying in size, shape, water characteristics, stratigraphy, vegetation, and maintenance processes (C A Semeniuk 1988; C A Semeniuk *et al.*, 1990): from large linear lakes to small round or irregular seasonally damp wetland basins; from fresh water to hyposaline (brackish) to saline; from surface-water perching to groundwater recharged; their vegetation cover can vary from herbland to forest. These attributes are determined by regional features such as geology, geomorphology, soils, climate and hydrology, and local physical/chemical processes. The variety of wetlands thus formed has been aggregated into natural groupings that have been termed *consanguineous suites* (C A Semeniuk 1988), and these are related to geomorphic setting.

In this paper, the wetlands for stratigraphic study have been drawn from the following consanguineous suites: 1. Becher Suite; 2. Yanchep Suite; 3. Stakehill Suite; 4. Coogee Suite; 5. Balcatta Suite; 6. Bibra Suite; 7. Pinjar Suite; 8 Jandakot Suite; 9 Gnangara Suite; 10. Riverdale Suite; 11. Bennett Brook Suite, and 12. Mungala Suite.

Sediment types

Based on composition and texture, Semeniuk & Semeniuk (2004) recognised ten end-member sediment types in wetlands of the Spearwood Dunes, Bassendean Dunes and Pinjarra Plain on the Swan Coastal Plain, focused only in the central Swan Coastal Plain mainly between Moore River and Mandurah; *viz.*, 1. peat; 2. peat intraclast gravel and sand; 3. calcilutite; 4. carbonate skeletal gravel and sand; 5. carbonate intraclast gravel and sand; 6. diatomite; 7. diatomite intraclast gravel and sand; 8. kaolinitic mud; 9. quartz sand; and 10. quartz silt. However, for completeness of this paper, the full range of the sediments occurring in wetlands of the Quindalup Dunes are included here (C A Semeniuk 1988, 2006). Basins in the Quindalup Dunes contain, as end-member sediments, calcilutite, peat, quartzo-calcareous sand of aeolian origin and, locally, stromatolitic boundstone. Therefore, for purposes of this paper, incorporating the geomorphic settings of Quindalup Dunes, Spearwood Dunes, Bassendean Dunes and Pinjarra Plain, and encompassing the full climatic range of the Swan Coastal Plain from the Bunbury region to Moore River, in total there are 12 end-member wetland sediment types (Table 2).

Mixtures of these end-member sediment types, contributions to peat and diatomite from sponge spicules and phytoliths, and mixtures between the primary sediments and quartz sand (that forms the basement or the margins to the wetland deposits) also occur (Semeniuk & Semeniuk 2004), resulting in spongolitic peat, diatomaceous peat, calcilutaceous peat, spongolitic diatomite, peaty sand, and muddy sand (calcilutaceous muddy sand, diatomaceous muddy sand, and kaolinitic muddy sand), amongst others. The end-member sediment types and the main mixtures between them are described in Table 2 in terms of three sediment suites, *viz.*, fine grained wetland sediments (including both autochthonous and allochthonous sediments), sand/gravel fine grained wetland sediments, and muddy sand wetland sediments.

While Semeniuk & Semeniuk (2004) list and describe a wide range of wetland sediments (see Table 6, *op. cit.*), in places in this paper, the range of fine-grained biogenic wetland sediment types are simplified into three main biogenic sediment groups (the peat-dominated group, the diatom-dominated group, and the calcilutite-dominated group) to convey the three main sources of fine-grained biogenic material contributing to wetland sediments, with the caveat that intergradations between the end-member sediments will occur. The "peat group" contains peat *sensu stricto* (after Semeniuk & Semeniuk 2004), diatomaceous peat, and calcilutaceous peat, the "diatomite group" contains diatomite, organic matter enriched diatomite and calcilutaceous diatomite, and the "calcilutite group" contains organic matter enriched calcilutite and diatomaceous calcilutite.

Geographic distribution of wetland surface sediment types

Surface sediments underlying wetlands vary in their composition east to west across the Swan Coastal Plain according to geologic and geomorphic setting, extant regional to subregional host water chemistry, and biota. The various consanguineous wetland suites of C A Semeniuk (1988) also reside in different geologic and

Table 2

Description of wetland sediments (summarised from Semeniuk & Semeniuk 2004)

Sediment type	Description[1]
Fine grained sediment suite	
peat	black to grey, brown, homogeneous to root-structured to finely laminated, mainly fine-grained organic matter, with root fibres, plant detritus and scattered sand, and freshwater snails (or fragments); some peats with branches, twigs, and logs; often containing diatoms, phytoliths, and sponge spicules; organic matter content > 75%
diatomaceous peat (and spongolitic diatomaceous peat)	peat as above, but with 50–75% organic matter content, and with significant diatom content, and often significant sponge spicule content
calcilutaceous peat	peat as above, but with 50–75% organic matter content, and with significant carbonate mud content
diatomite (and spongolitic diatomite)	light grey, locally dark grey in humus-rich upper layers, homogeneous to root-structured at the surface and laminated at depth; consists of silt-sized to clay-sized diatom tests and particles (and sponge spicules)
organic matter enriched diatomite	grey to brown homogeneous diatomite, as above, but with 25–50% content of organic matter
organic matter enriched calcilutite	grey to brown homogeneous calcilutite, as above, but with 25–50% content of organic matter
calcilutite	cream to pink to grey homogeneous, laminated, burrow-mottled, root-structured, bioturbated, or colour mottled; consists dominantly of clay-sized carbonate particles; mainly calcite, with minor Mg-calcite, aragonite and dolomite, or locally dominantly dolomite; with freshwater snails or fragments
kaolinitic mud[2]	white, orange, dark brown, dark grey to black, homogeneous to root-structured, mostly mud-sized particles with scattered sand; kaolinitic mud is mainly kaolinite, but locally some montmorillonite and sericite; diatoms, sponge spicules and phytoliths are also present
quartz silt	cream to light grey, and structurally homogeneous to root-structured, silt-sized and some clay-sized silica particles, with scattered quartz sand; diatoms, sponge spicules and phytoliths are also present
Sand/gravel sediment suite	
peat intraclast gravel and sand	black to grey, breccioid often termed "peat breccia" in this paper to conglomeratic, grading to sand-sized clasts of peat, or alternating layers of breccia, conglomerate, and sand-sized fragments of indurated peat; may be texturally layered, and root-structured
carbonate skeletal gravel and sand	cream to grey, homogeneous to layered; very coarse to medium sand; consists of whole and fragmented skeletons of molluscs
carbonate intraclast gravel and sand	cream to grey, structurally homogeneous to layered, with local vesicular to fenestral structures; consists of medium, coarse to very coarse intraclasts of calcilutite or cemented aggregates of carbonate sand
diatomite intraclast gravel and sand	light grey, rounded fine gravel- to sand-sized clasts of diatomite
quartz sand[3]	white, light grey to dark grey sand, homogeneous to bioturbated to root-structured; locally with wispy lamination, or with vesicular structure; quartz, with minor feldspar
quartzo-calcareous sand	white, light grey to dark grey sand, homogeneous to bioturbated to root-structured; consists of quartz, carbonate grains
Muddy sand sediment suite	
peaty sand	quartz sand as above, but with fine-grained interstitial material with > 75% organic matter
calcilutaceous muddy sand	quartz sand as above, but with interstitial carbonate mud
diatomaceous muddy sand	quartz sand as above, but with interstitial diatom mud
kaolinitic muddy sand	quartz sand as above, but with interstitial mud-sized phyllosilicate mineral particles and quartz silt

[1] there is also a range of diagenetic products that form in wetland sediments (Semeniuk & Semeniuk 2004); these include carbonate cements and nodules, micro-etched surfaces (indicating dissolution) on biogenic silica, the bio-mediated precipitates of FeS_2 as framboidal pyrite, the sulphides of heavy metals and metalloids; these diagenetic products are not described in detail here.

[2] the sediments formed as mixtures between kaolinitic mud and the biogenic mud of peat, diatomite, and calcilutite (Semeniuk & Semeniuk 2004) are not common sediments (the most common of this suite being organic matter-enriched kaolinitic mud, diatomaceous kaolinitic mud, and organic matter-enriched diatomaceous kaolinitic mud).

[3] quartz sand here is not the parent basement sand, but extrabasinal, transported *into* the wetland basin.

geomorphic settings, each often with its own diagnostic basement materials such as quartzo-calcareous sand, limestone, yellow quartz sand, white quartz sand, and fluvial terrigenous sediments. As a consequence, sediment types filling wetland basins, or forming along the margins of the basins reflect these geomorphic and consanguineous settings: firstly, because of the hydrochemical setting, and secondly because of the direct sediment contribution from the surrounding uplands (*e.g.*, quartz sand shed by sheet wash or wave reworking into wetland margins in the Bassendean Dunes, quartzo-calcareous sand shed by sheet wash, wave reworking, or aeolian agency into wetland margins in the Quindalup Dunes, or fluvial clay delivered by rivers and alluvial fans into basins on the Pinjarra Plain).

Wetland hydrochemistry and hence sediment types reflect regional to local hydrochemistry, as determined by source of water (local groundwater, subregional groundwater, meteoric water, and surface water inflow), or by intrabasinal perturbations. For example (as noted above), groundwaters residing in quartz-sand-rich terrain (such as the Bassendean Dunes) will be Ca-and-HCO_3 depauperate, and groundwaters residing in limestone terrain (such as the Spearwood Dunes) and calcareous coastal dunes (such as the Quindalup Dunes) will be locally Ca-and-HCO_3 enriched (Table 1).

Wetland hydrology and hydrochemistry underpin biotic responses and hence will influence the type of biogenic sediment that may accumulate. There will be a variety of biogenic sedimentary fills in any east-west transect in relation to hydrochemistry and geomorphic setting. Sediment type may be the direct product of biogenic activity, producing particles that accumulate *in situ* or are transported to other sites in the basin: vegetation contributes to the development of fibrous and massive peat, and development of organic matter enriched calcilutite and diatomite; diatoms contribute to the development of diatomite, diatomaceous peat and diatomaceous calcilutite; and charophytes and calcareous invertebrate fauna contribute to the development of calcilutite, calcilutaceous peat and calcilutaceous diatomite.

There also will be a pattern in the distribution of wetland surface biogenic sediment types geographically from south to north in relation to climate. For instance, climate affects the geographic distribution, abundance, and productivity of plant forms and species. As a consequence, for example, similar wetland basins residing in the Bassendean Dunes may be peat dominated in the southern wetter parts of the Swan Coastal Plain, and diatomite dominated in the drier northern parts of the Plain. The occurrence and productivity of plant forms also will vary across a wetland basin, and hence regulate the type of sediment filling different parts of the basin.

A description of surface sediments of wetland basins across the Swan Coastal Plain, from the Pinjarra Plain to the Quindalup Dunes in relation to their geological and hydrochemical setting is provided below.

Wetland basins on the Pinjarra Plain along the eastern Swan Coastal Plain range from lakes to sumplands to damplands, and are associated with terrigenous sediments of river courses. The sumplands and damplands tend to be shallow depressions underlain by extrabasinal sediments, such as sand, kaolinite-dominated mud and muddy sand, reflecting sediment delivery and sedimentation by fluvial processes. Basin fills within the Pinjarra Plain are kaolinitic mud, muddy sand, sand, or peat. Diatoms and phytoliths contribute subdominant to minor fine-grained biogenic silica to such sediments as fine grained interstitial material (Semeniuk & Semeniuk 2004).

Within the Bassendean Dunes, the basins reside in a terrain of quartz sand, and the wetlands are lakes, sumplands, and damplands. The waters tend to be cation-poor, tannin-rich, and acidic (to alkaline). The surface sediments underlying the wetlands are intrabasinal peat, diatomaceous peat, and diatomite, and extrabasinal kaolinitic mud, and quartz sand. Within the Spearwood Dunes, the basins reside in a terrain of quartz sand and/or limestone, and the wetlands are lakes and sumplands. The waters are cation-enriched and range from tannin-rich to tannin-poor, and alkaline (to acidic). The sediment fills are intrabasinal peat, diatomaceous peat, or calcilutite, and extrabasinal quartz sand. Surface sediments underlying wetlands are peat, diatomaceous peat, calcilutite, organic mater enriched calcilutite, and locally, quartz sand. Within the Quindalup Dunes, the basins reside in a terrain of quartzo-calcareous sand and the wetlands are lakes, sumplands, and damplands. The groundwaters are cation-enriched, and range from tannin-rich to tannin-poor, and alkaline (to acidic). The sedimentary fill is intrabasinal calcilutite, and some peat, and extrabasinal quartzo-calcareous sand.

The occurrence of the surface wetland sediments with respect to the wetlands studied on the Swan Coastal Plain is presented in Figure 7. For purposes of this illustration, the wide range of wetland sediment types are simplified into the three fine-grained biogenic groups (*viz.*, peat, diatomite, calcilutite), and two types of terrigenous sediment (*viz.*, kaolinite mud, and extrabasinal sand). In many wetlands, there are strong internal facies changes within the central zone, so that two or more sediments are used to characterise that particular wetland. Facies changes at the margin (periphery) of wetlands (such as organic matter enrichment, or muddy sand facies) are ignored in this presentation. In a number of wetlands, typical of those in the Bassendean Dunes, there is no wetland sediment but rather waterlogged basement sand (these are noted as "sand" on the map). Figure 7 does not address lithologies that may be present at depth (*i.e.*, if the surface sediment is calcilutite, and the subsurface sediment at > 30 cm depth is diatomite, the extant surface sediment is noted as calcilutite). In general therefore, each sampling site is noted by a single sediment type. However, where two sediment types are co-dominant in a basin, both are included at that site on the map. For muddy sands, the mud component only is noted on the map (*e.g.*, calcilutaceous muddy quartz sand is noted as calcilutite, as the generation of carbonate mud is considered to be the critical factor in showing the distribution of sediments in relation to geomorphic and geographic setting even if that carbonate mud is admixed with parent quartz sand). However, using only the mud component of muddy sands in the map of Fig. 7 was not a major issue in this study as most wetland basins encountered usually were clearly dominated by fine-grained wetland sediment.

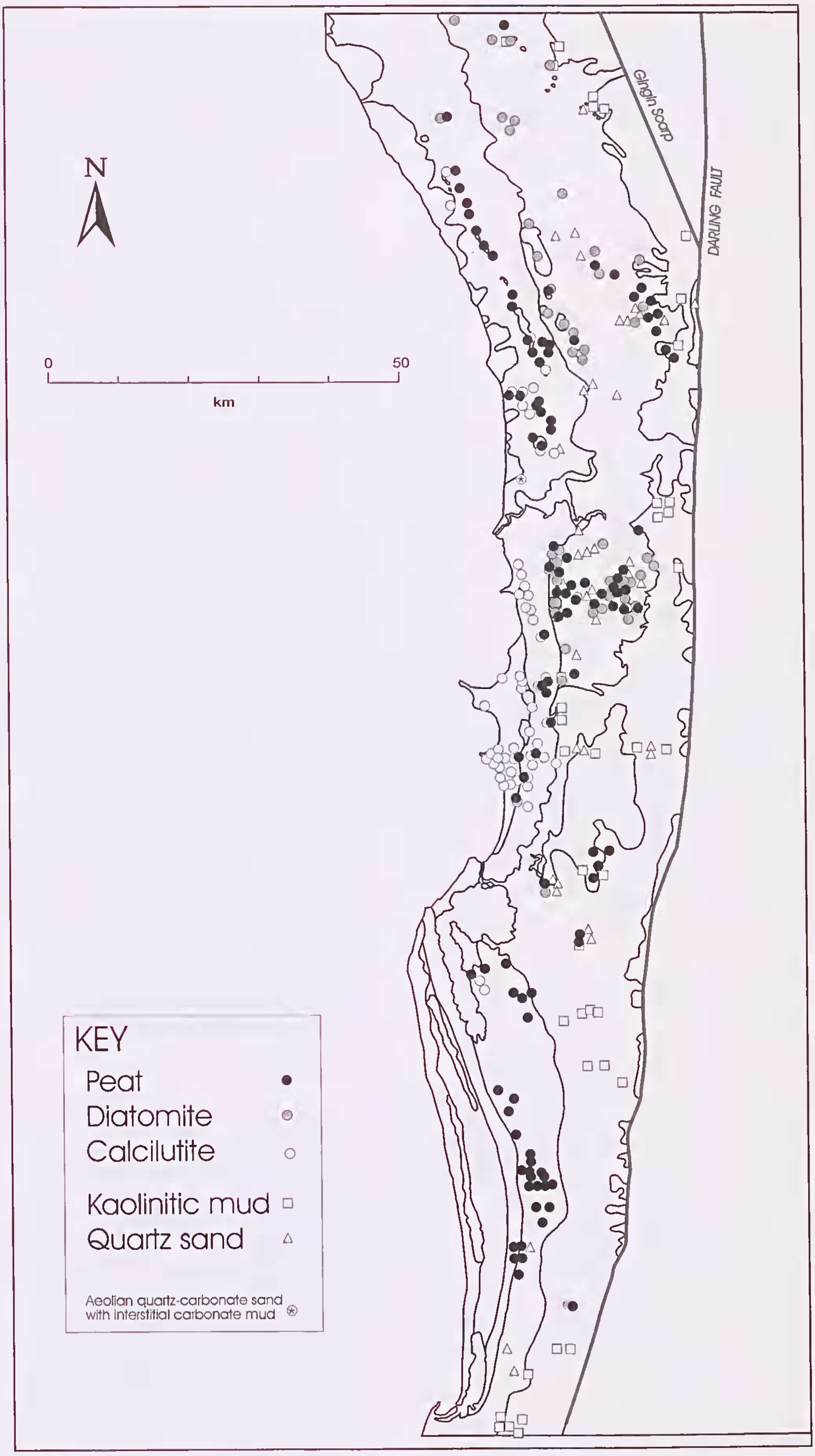


Figure 7. Sediment types at the sampling sites, showing the dominant sediment in the wetland. The outline of the geomorphic units in Figure 5 is shown unlabelled in this illustration to indicate the relationship of sediment type to geomorphic setting, and the reader will need to refer to Figure 5 to determine the geomorphic setting of a particular sampling site.

Table 3

Dominant surface sediment types in key consanguineous wetland suites, central Swan Coastal Plain in relation to geomorphic setting and lithology through which source (telluric) groundwater has been derived.

Geomorphic setting	Consanguineous wetland suite	Lithologic context for telluric water	Dominant surface sediment type[1,2]
Quindalup Dunes	Becher	calcareous sand	calcilutite, and organic matter enriched calcilutite
Quindalup Dunes	Peelhurst	calcareous sand	calcilutite, organic matter enriched calcilutite, and quartzo-calcareous sand
Quindalup Dunes	Cooloongup	calcareous sand and limestone	calcilutite, intraclast sand and gravel, stromatolitic boundstone
Spearwood Dunes	Yanchep	limestone and quartz sand	calcilutite, peat, diatomaceous peat
Spearwood Dunes	Stakehill	limestone and quartz sand	calcilutite, peat
Spearwood Dunes	Coogee	limestone and quartz sand	calcilutite
Spearwood Dunes	Balcatta	quartz sand and limestone	peat, calcilutite
Spearwood/Bassendean Dunes contact	Bibra	quartz sand	diatomite, (and organic matter enriched diatomite)
Spearwood/Bassendean Dunes contact	Pinjar	quartz sand	diatomite
Bassendean Dunes	Gnangara	quartz sand	diatomite, peat
Bassendean Dunes	Jandakot	quartz sand	diatomite, peat
Bassendean Dunes	Riverdale	quartz sand	peat, diatomaceous peat
Bassendean Dunes/ Pinjarra Plain contact	Bennett Brook	quartz sand, muddy sand	kaolinitic mud, muddy sand, sand, peat
Pinjarra Plain	Mungala	quartz sand, muddy sand	kaolinitic mud, muddy sand, sand

[1] lithologic terms for the sediments, and the range of sediment types occurring within a consanguineous suite may differ from those in C A Semeniuk (1988), firstly, because the wetland sediment terms have been refined (following Semeniuk & Semeniuk 2004), and secondly, because more detailed work has been carried out in the wetland suites.

[2] the variation in sediments within a suite can occur as a result of sediments varying from wetland to wetland within a suite, and also can reflect the variation of sediments across a given basin and down the stratigraphic profile.

A summary of the east-west pattern of sedimentary fills in wetlands related to consanguineous setting is presented in Table 3.

Intrabasin variation in surface sediment types

Surface sediments can vary laterally within a given basin, *i.e.*, there can be facies variation within basins. The most prominent and consistent variation is that of sediments of the central part of a basin grading into the sediments along the margin of a basin. Peat, diatomite, calcilutite, or kaolinitic mud of the central basin grade into peaty sand, diatomaceous muddy sand, calcilutaceous muddy sand, or kaolinitic muddy sand, respectively along wetland margins. Peat, diatomite, calcilutite, or kaolinitic mud of the central basin also may adjoin aprons of quartz sand, peat intraclast sand/gravel, diatomite intraclast sand/gravel, carbonate intraclast sand/gravel, and shell sand/gravel. Facies changes also are noted where diatomite or calcilutite of non-vegetated central parts of a basin grade into a zone of peripheral vegetation (with concomitant increased production of macrophytes and accumulation of organic matter and sponge spicules); this results in a peripheral zone of sediment composed of organic matter enriched diatomite, spongolitic organic matter enriched diatomite, organic matter enriched calcilutite, spongolitic organic matter enriched calcilutite, peat, or spongolitic peat. Facies changes also occur *within* the central basin: for example, diatomite, calcilutite or peat may be laterally facies equivalents of each other. Such intrabasin lateral facies variation often reflects various types of water regimes within a basin, or local microscale topographic variation, or where vegetation type strongly influences sediment type, the mottling and heterogeneity of vegetation (*cf.* C A Semeniuk *et al.* 1990)

Wetland stratigraphy

Wetland stratigraphy is described in terms of the main sedimentary sequence filling the central basin, and its variation, and in terms of its basal and marginal contacts. The intrabasinal depositional categories of Semeniuk & Semeniuk (2004), *viz.*, central facies, basal facies, and marginal facies are used here. Note should be made that while Semeniuk & Semeniuk (2004) emphasised the Pleistocene age of the basement that formed the foundation to wetland basins in the Spearwood Dunes, Bassendean Dunes and Pinjarra Plain systems, wetland basins within the Quindalup Dunes reside in a terrain of Holocene age (C A Semeniuk 2006). Hence, as noted earlier, the basement to wetland basins can be Pleistocene sediment, or Holocene sediment. The variation in wetland stratigraphy is shown in Figures 8, 9, 10 and 11.

Figure 8 shows a range of cores, illustrating lithology and structures, down-profile variation in lithology, contact types, across-basin facies changes, and some specific features such as burrow structures, charcoal horizons, and breccia (*i.e.*, intraclast) units. The details of these cores shown in Figure 8 also supplement the stratigraphic sections shown in Figures 9, 10 and 11 by providing lithologic detail for some selected stratigraphic sequences. The core from Lake Cooloongup illustrates sedimentary structures, bioturbated contacts, the capping of a calcilutite sequence by peat, and the gradational relationship between calcilutite and underlying sand. The cores from Lake Gwelup show the lateral change in a stratigraphic contact between (shelly) organic matter enriched calcilutite and underlying calcilutite; it grades from sharp contact to burrowed contact over 20 m. The cores from Lake Manning show burrow-punctured laminated calcilutite and colour variation in the laminated calcilutite from the central basin, decimetre-interlayered organic matter enriched calcilutite and grey calcilutite from the marginal facies, and the muddy sand contact between calcilutite and underlying sand in the basal facies under the central basin. The core from Lake Coogee shows grey, laminated calcilutite overlying, with sharp contact, a layered to burrow-structured shelly and intraclastic calcilutite. The core from Beenyup Swamp shows an upper part of fibrous peat interlayered on a decimetre scale with diatomaceous peat, and a lower (deeper) section composed of root-structured, bioturbated, fibrous peat with charcoal horizons. The cores from Lake Mealup show stratigraphic variation over 20 m: laminated peat is overlain by brecciated peat in one core, and by root-structured, bioturbated, fibrous peat and then brecciated peat in another core. The surface cores of peat breccia from Beenyup Swamp, Lake Mealup, and Melaleuca Park show the relationship of peat breccia to an underlying microbrecciated peat, crudely laminated peat, and root-structured, bioturbated, fibrous peat, respectively.

Figure 9 shows a range of lithological sequences to illustrate the variety of stratal types in the wetlands, and a variety of sedimentary fill thickness, focusing on the stratigraphy of groups of sections exhibiting terrigenous sediment dominated sequences, diatomite-dominated sequences, peat-dominated sequences, calcilutite-dominated sequences, peat sand dominated sequences, and mixed (lithologic) sequences. The cores of biogenically derived sediment (diatomites, peats, and calcilutites) generally show the gradational muddy sand transitional zone between fine grained biogenic sediment and the underlying basement sand, however, one core (Site 6) at Casuarina Swamp shows a relatively thick sequence of diatomaceous muddy sand. The cores illustrating mixed lithologic sequences show quite variable interlayering of lithology from site to site, with no regionally consistent pattern.

Figures 10 and 11 illustrate cross-basin stratigraphy and stratigraphic relationships for a variety of small to large wetlands that are peat-dominated, diatomite-dominated, calcilutite-dominated, those with mixed lithologic sequence, and those filled with terrigenous sediment. These cross sections, to be described later in the paper, illustrate variation in ancestral basin profile, asymmetry in wetland basin fill, variation in thickness of the sedimentary fill, asymmetry in stratigraphy, and various types of basal and lateral facies relationships.

The central facies – the main sedimentary fill

The types of sediments filling wetlands may form varying sequences within the main body of the wetland, *i.e.*, the central facies of the wetland sedimentary fill. The stratigraphy may be composed entirely of a single fine-grained end-member sediment type (*e.g.*, diatomite, or peat), homogeneous mixtures of the end-member sediment types (*e.g.*, diatomaceous peat, or organic matter enriched calcilutite), interlayered sequences of the sediments, texture-mottled mixtures of the end-member sediments, or interlayered sequences of lithologically similar but structurally distinct layers. Figure 9 illustrates a selection of stratigraphic profiles, as single cores, from peat-dominated wetlands, diatomite-dominated wetlands, calcilutite-dominated wetlands, terrigenous sediment dominated filled wetlands, and those with mixed stratigraphy.

Sediment fill in wetland basins, as measured in the basin centre, varies in thickness from 0.1 m to 7 m. Most wetland sedimentary fill in basins on the Swan Coastal

Table 4

Standard stratigraphic sequences within Swan Coastal Plain wetlands

Style of stratigraphy	Type location
thick peat (> 2 m)	Karrinyup Road Swamp
thick peat and diatomaceous peat (> 2 m)	Waluburnup Swamp
medium thickness peat and diatomaceous peat (1–2 m)	Stakehill Swamp
thin peat and diatomaceous peat (< 1 m)	Melaleuca Park Swamp
thick calcilutite (> 2 m)	Lake Manning
thin calcilutite (< 1 m)	Cud Swamp
thin calcilutaceous muddy sand (< 0.1 m)	1N Becher wetlands
thin peat on thin calcilutite	Wawa Swamp
thin diatomite on thick calcilutite	Lake Forrestdale
alternating peat and calcilutite	Leda Swamp
peat, calcilutite, quartz sand	Little Carine Swamp
peat, kaolinitic mud, quartz sand	Ellenbrook Swamp
thick diatomite (> 2m)	North Lake
thin diatomite and diatomaceous sand	Lake Pinjar
diatomite, kaolinitic mud, quartz sand	Coonabidgee Swamp

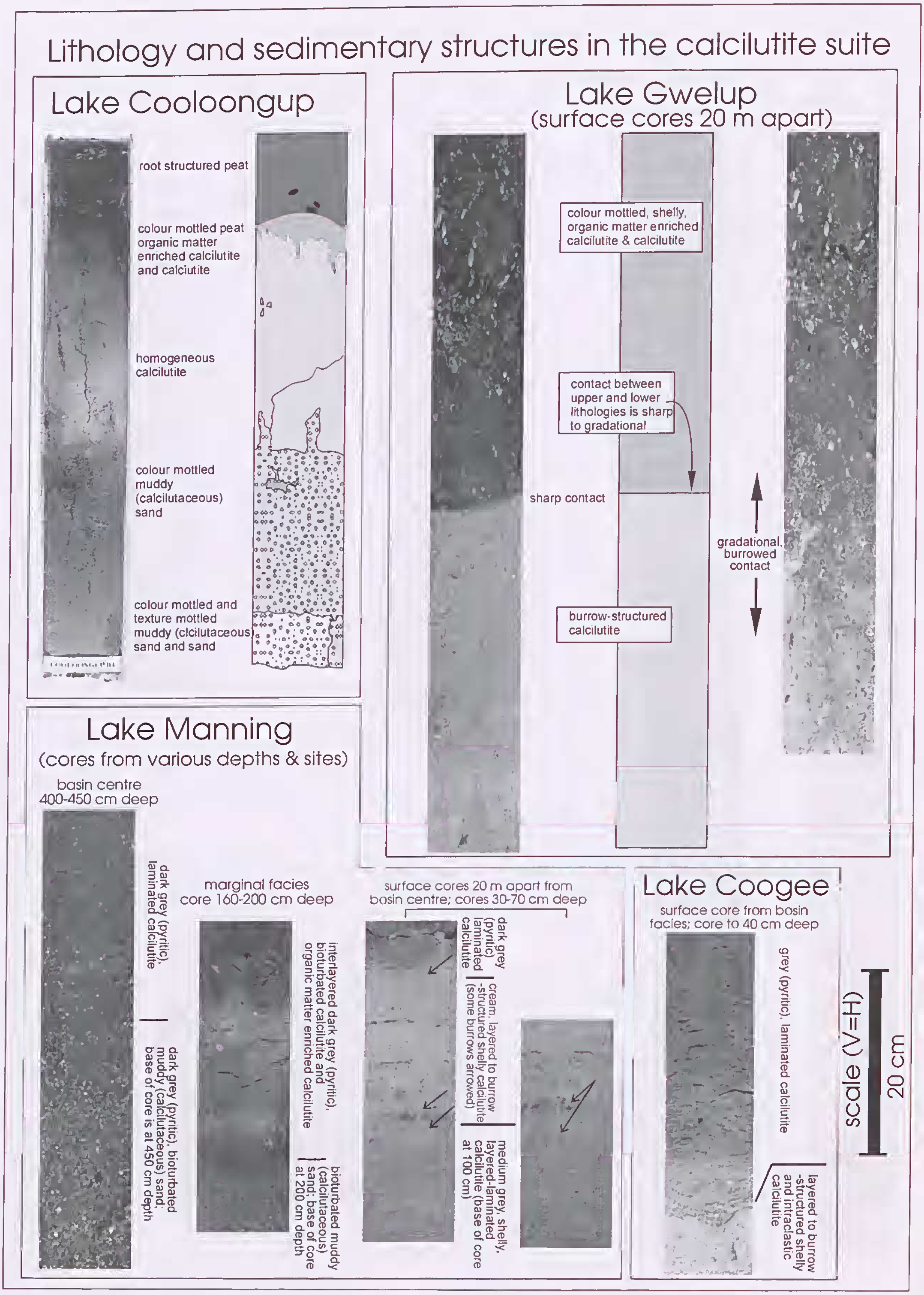


Figure 8. Selection of single-cores to illustrate the range of structures present in the sediments. Core relate to selected sites and depths of cores and transects shown in the illustrations of Figures 9 and 10.

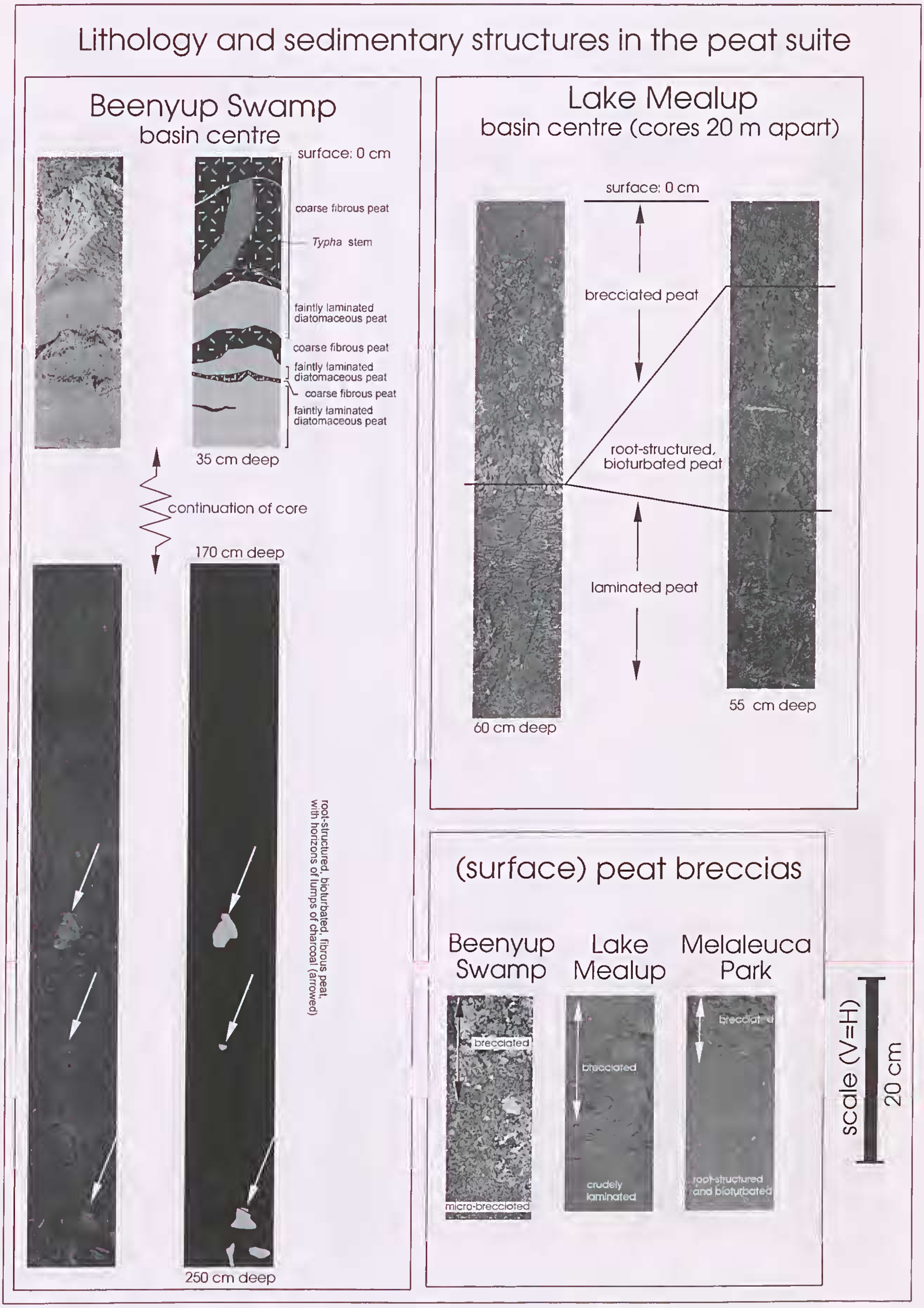


Figure 8 (cont.)

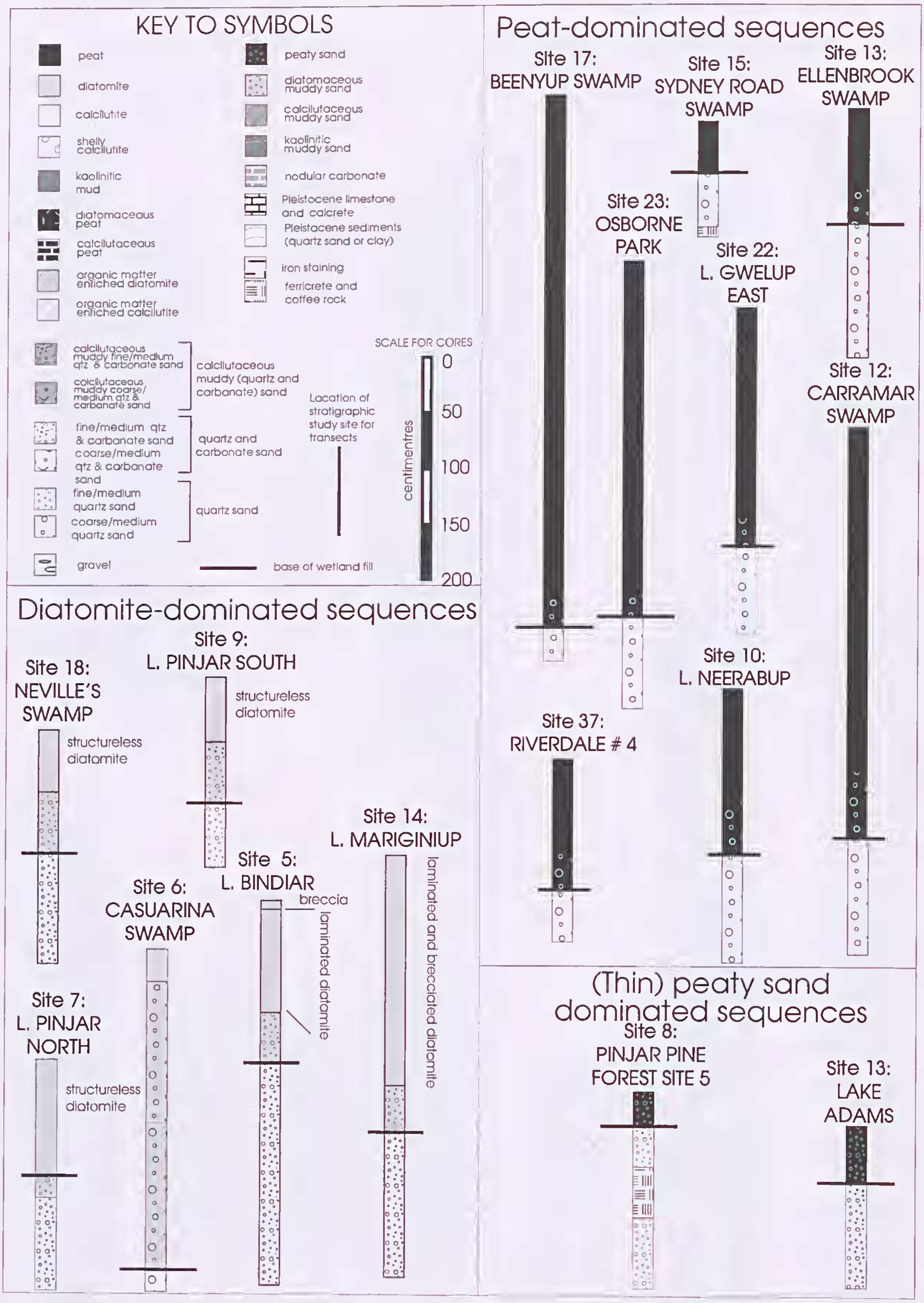


Figure 9. Selection of single-core stratigraphic profiles from various wetlands from sites 1–37 of Figure 4 showing sequences that are peat-dominated, diatomite-dominated, calcilutite-dominated, terrigenous sediment dominated, and of mixed lithology. Location of cores is shown in Figure 4. The lithologies of quartz and carbonate sand, and their muddy sand equivalents, are simplified from C A Semeniuk (2006), and apply only to the wetlands in the Becher Suite. Key to lithologies in this Figure also applies to the Transects shown in Figures 10 and 11.

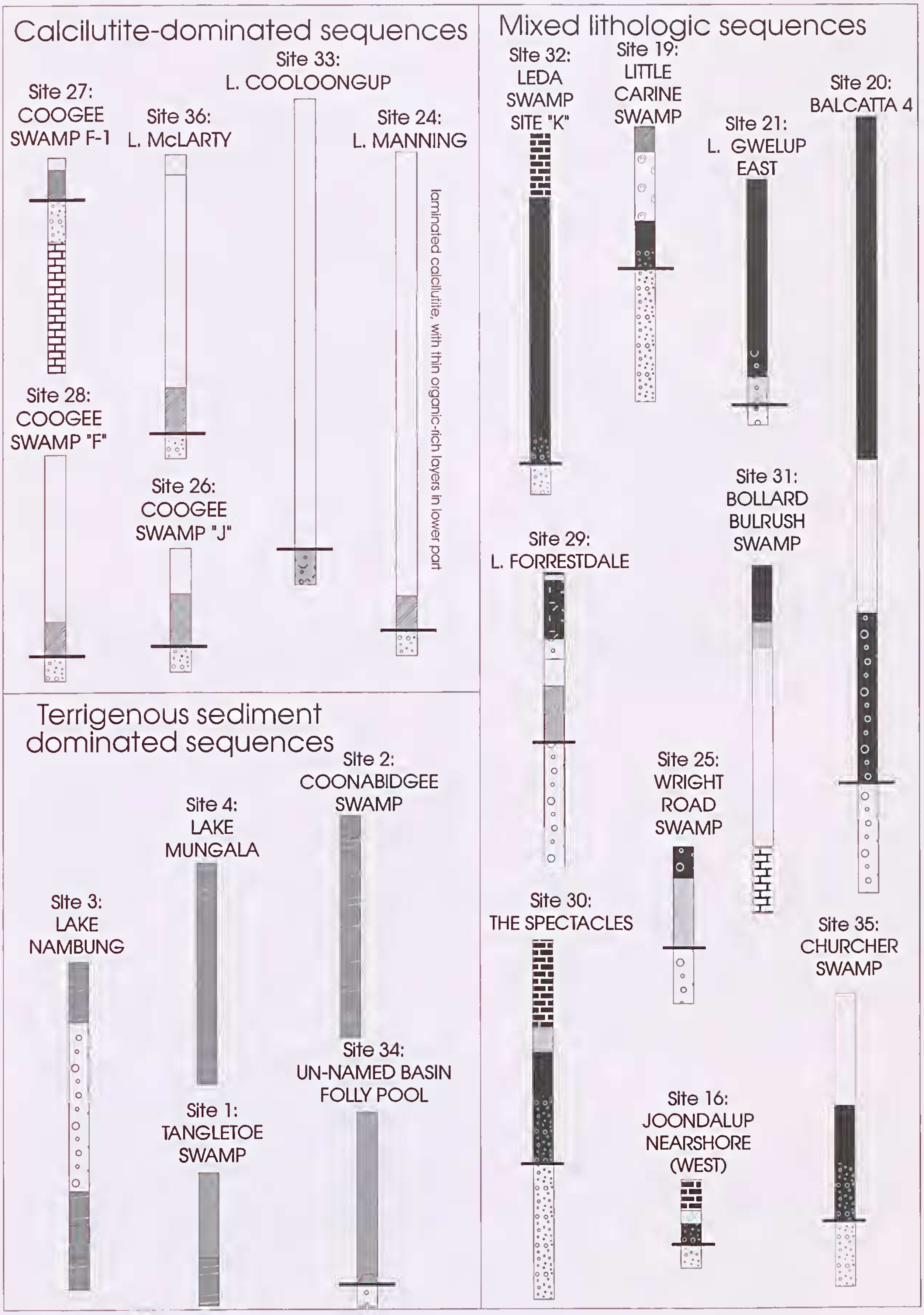


Figure 9 (cont.)

Plain is 1–1.5m thick. Peats range from 0.3 m to 7 m; calcilutites range from 0.2 m to over 4 m; diatomites range from 0.1–3 m generally; and kaolinitic mud deposits range from 0.1–0.2 m.

Fifteen standard sequences are recognised in the sedimentary fill of wetlands in the Quindalup Dunes, Spearwood Dunes, Bassendean Dunes, and Pinjarra Plain. These standard sequences, with some variation in thickness of units therein, recur throughout the wetlands of the Swan Coastal Plain. The standard sequences and type locations (where best developed) are listed in Table 4.

Locally, in some wetlands, there is lateral stratigraphic variation in the interior of the wetland sedimentary fill, *i.e.*, intrabasin lateral variation of stratigraphy of the central facies that reflect, originally, isochronous intrabasin lithologic variation rather than diachronous vertically accreting lithologies. Some of the isochronous lateral variations involve changes in lithology from peat to diatomite, or fibrous peat to laminated peat, or peat to calcilutite. Where directly observable (because of engineering excavations and dewatering), these stratigraphic changes appear as lithologically distinct lenses with sharp to gradational boundaries.

Contact of the main sedimentary fill to the basement

The base of wetland fills tends to be gradational into the underlying Pleistocene or Holocene materials. Peat, diatomite, or calcilutite overlying basement quartz sand have a gradational zone of infiltrated or bioturbated wetland sediment resulting in peaty sand, diatomaceous sand and calcilutaceous sand, respectively (Figures 9, 10, and 11).

The marginal facies

The marginal facies of the wetland sedimentary fills reflect two processes: 1. changes in lithology in wetland sediments in margin situations; and 2. the interaction of wetland sediments with the basement materials within which the wetland resides. As a result, two types of marginal facies are recognised: the inner marginal facies derived directly from the main sedimentary fill of the wetland, and an outer marginal facies derived from the mixing of wetland sediment with basement material. In many instances, the inner marginal facies is mixed with basement material to form a plethora of sediment types in the outer marginal facies.

The development of the inner marginal facies results from the fact that wetland margins are the environments, or facies, that experience extremes of physical environmental conditions. Additionally, they may support specific plant and faunal assemblages, or experience specific hydrochemical conditions (*e.g.*, such as Ca-enriched seepage from the upland into the wetland). Wetland margins, for instance, axiomatically, are the first parts of a wetland to dry out with the falling of water levels during the annual hydrologic cycle, and hence undergo desiccation, and hydrochemical changes (see below). They are the zones where fires may be concentrated, or where fires are most frequent, and hence may accumulate the products of pyrogenesis. Where there are seasonal hydrochemical changes, wetland margins may develop crusts, and other diagenetic products. If there is a peripheral vegetation zone, wetland margins may preferentially accumulate plant material and hence become enriched with organic matter. If there is a peripheral vegetation zone of sedges, they may preferentially accumulate concentrations of phytoliths. If there is a peripheral vegetation zone of trees or sedges, they may preferentially accumulate concentrations of sponge spicules. The shallow water margins are zones of foraging, burrowing and other faunal activities, resulting in bioturbation of sediments. If there is shoreward transport of sediment under wave action, wetland margins may accumulate shore-distinctive facies, such as shell ribbons, sand ribbons, or beachridges. Desiccation of peat, diatomite, and calcilutite may generate sheets of intraclast gravel and sand, which, by wave action, may accumulate as shore-parallel littoral ribbons, or as nearshore wave-oriented isolated ripples and bars.

The range of sediments that accumulate in the marginal facies in modern environments are listed according to their primary central basin lithology, *i.e.*, peat, diatomite, calcilutite (Table 5). It is stressed here that these marginal facies are not the product of wetland sediments interfacing with the basement materials but rather the facies changes that occur as wetland sediments are subjected to physical, chemical and biological processes associated with environmental conditions of shallow water, shoreline seepages, peripheral wetland biotic activities by fauna and flora, and drying out.

Wetland sediments also must interact with the basement material along their margins, producing a range of sediments types. The margins of the wetland

Table 5

Lithologies in the inner marginal facies derived from the three main fine-grained biogenic sediments

Primary central basin lithology	Inner marginal facies (in lateral contact with central facies)
peat	fibrous and root-structured peat, phytolith-bearing peat, spongolitic peat, peat intraclast gravel and sand (ie peat breccia and microbreccia) sandy peat
diatomite	structureless diatomite, root-structured diatomite, bioturbated diatomite, organic matter enriched diatomite, phytolith-bearing diatomite, spongolitic diatomite, diatomite intraclast gravel and sand, diatomaceous muddy quartz sand, sandy diatomite, sandy organic matter enriched diatomite
calcilutite	skeletal gravel and sand, organic matter enriched calcilutite, spongolitic calcilutite, root-structured calcilutite, bioturbated calcilutite, carbonate intraclast gravel and sand, sandy calcilutite, sandy organic matter enriched calcilutite

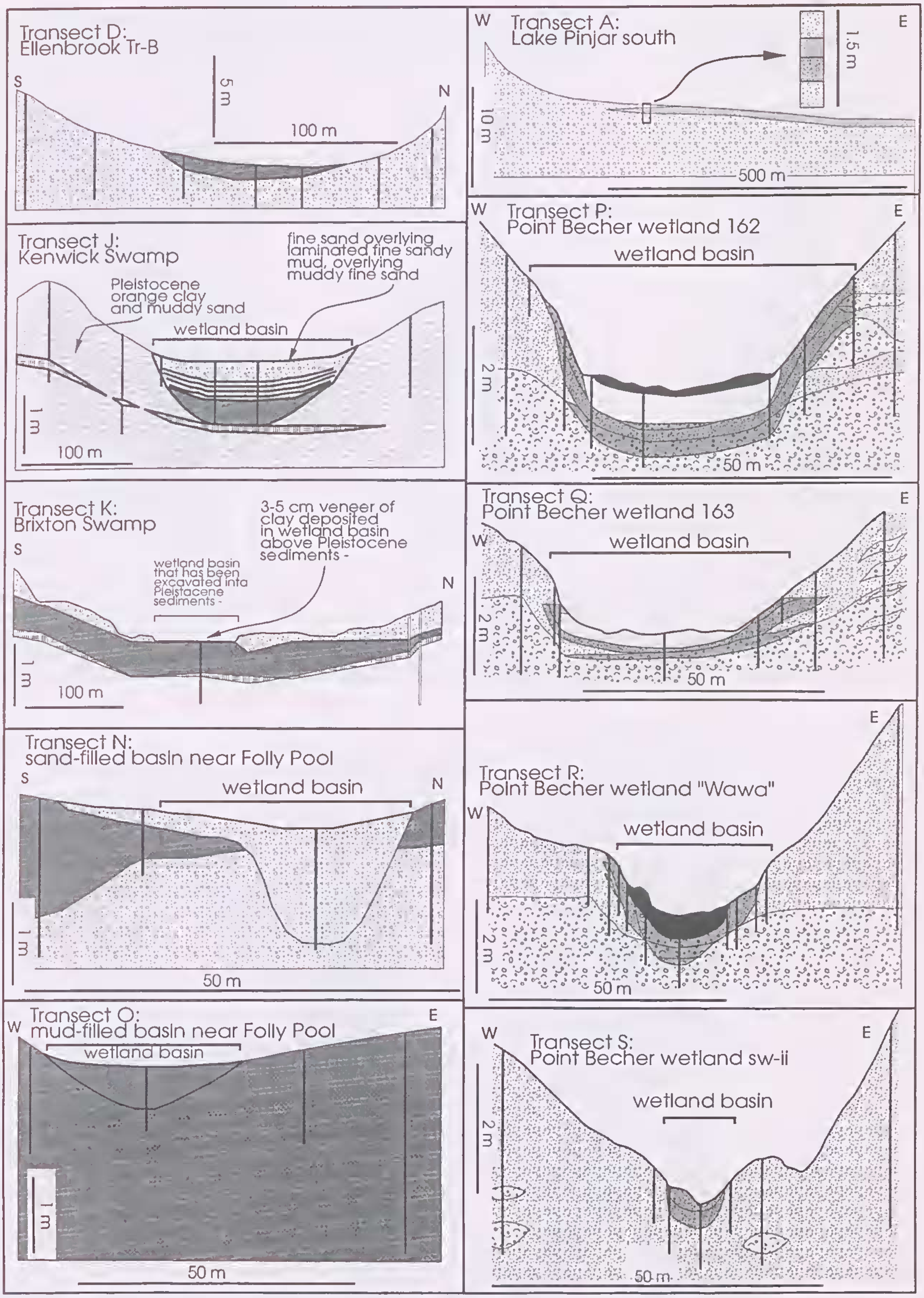


Figure 10. Stratigraphy of selected wetland basins from a number of locations, Transects A to V (excluding I), showing cross-basin variation in terms of lithological homogeneity or heterogeneity of sedimentary fill, and details of the central facies, and marginal and basal relationships. Location of cores is shown in Figure 4. Description of the transects is presented in the text. The cross sections from Point Becher (Transects P, Q, R and S) are modified from C A Semeniuk (2006). The extent of the wetland basin indicated on each transect provides indication generally of where high water levels reach.

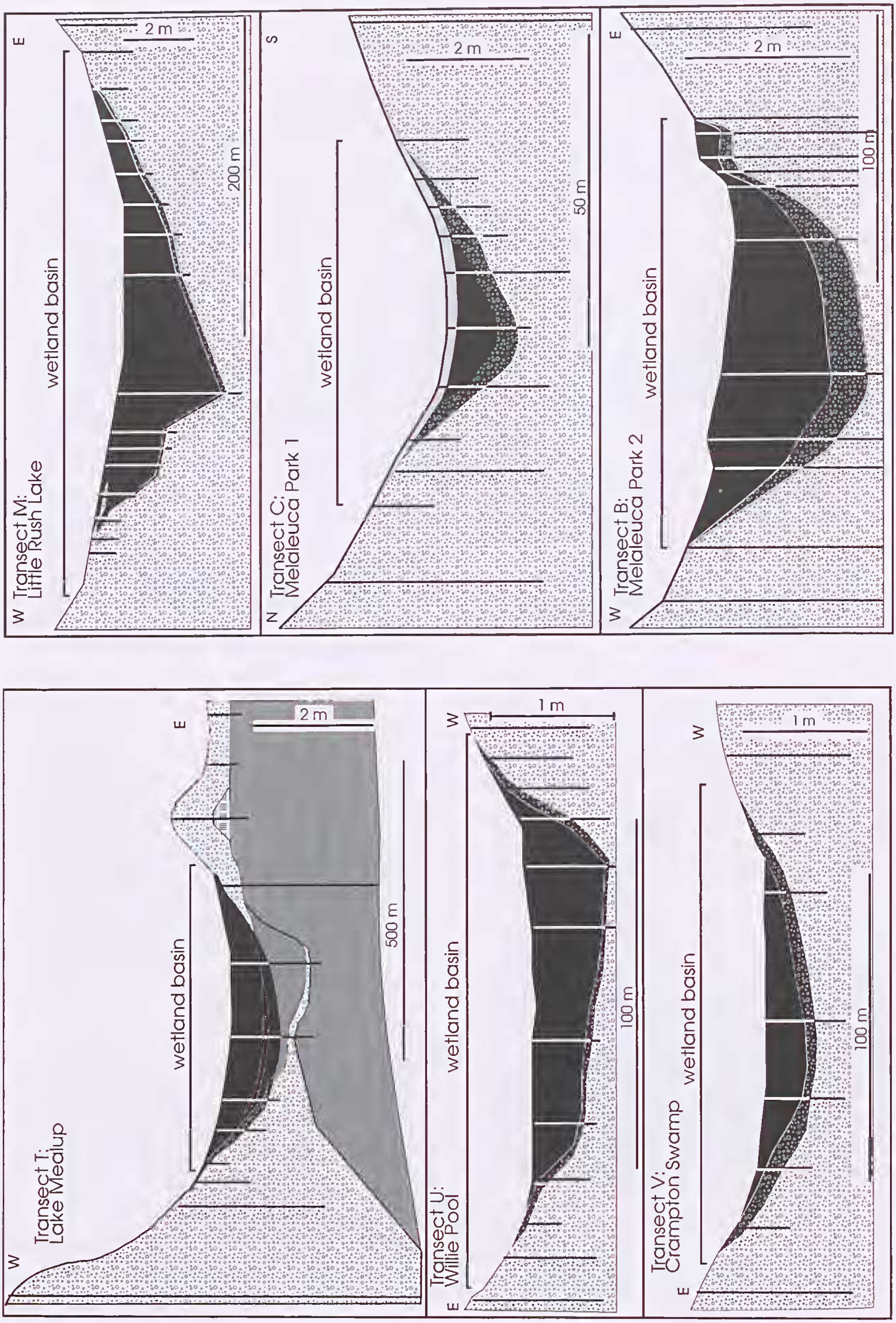


Figure 10 (cont.)

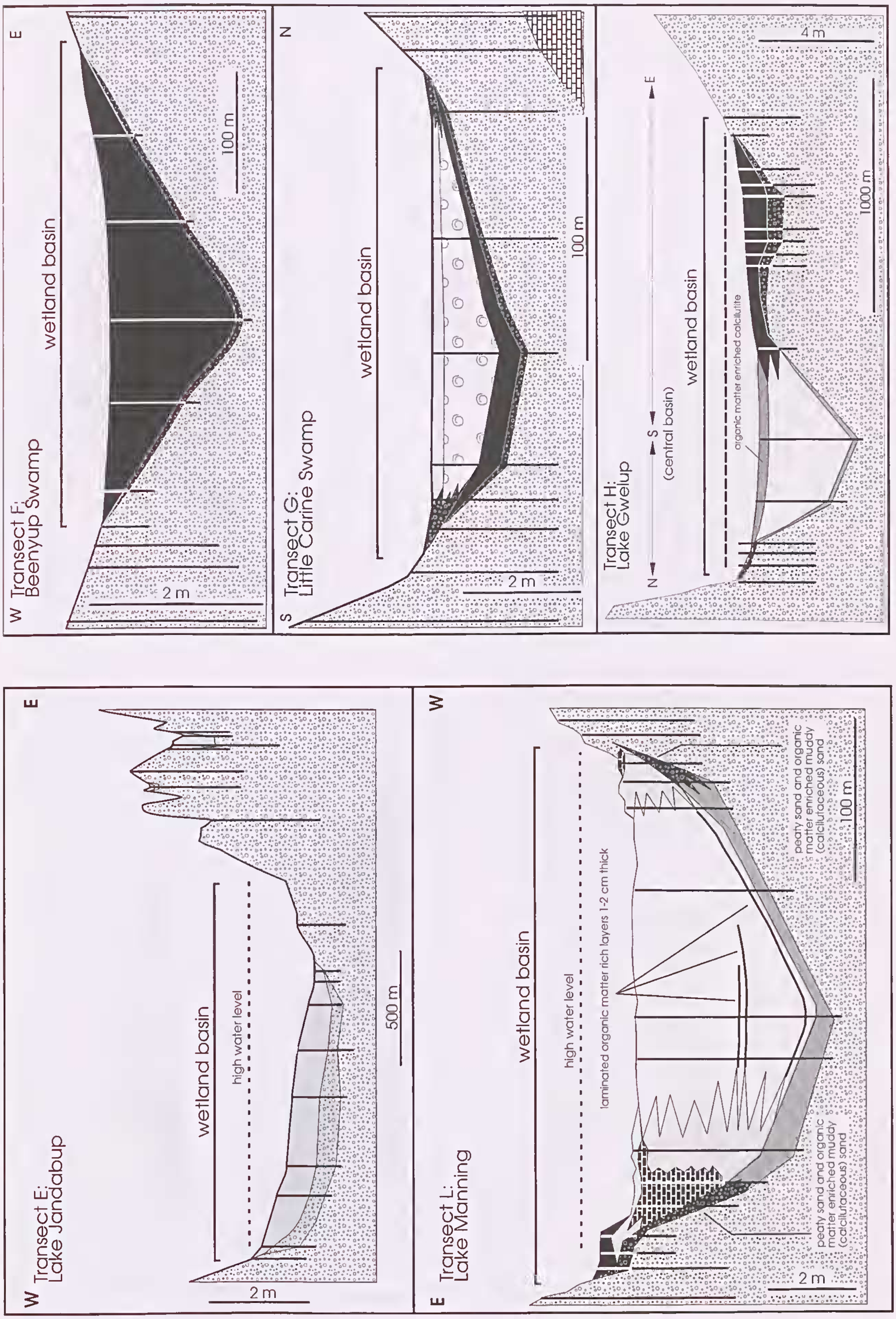


Figure 10 (cont.)

Table 6

Lithologies in the outer marginal facies derived from the three main fine-grained biogenic sediments

Primary central basin lithology	Outer marginal facies (in lateral contact with basement)
peat	peaty quartz sand, sandy peat
diatomite	diatomaceous muddy quartz sand, sandy diatomite, sandy organic matter enriched diatomite
calcilutite	calcilutaceous muddy quartz sand, calcilutaceous muddy quartzo-calcareous sand, sandy calcilutite, sandy organic matter enriched calcilutite

fills may have an interfingering relationship with reworked deposits of the surrounding Pleistocene or Holocene sediments (Figures 10 and 11), or may have a gradational contact. That is, peat, diatomite, or calcilutite of central wetland basins may grade laterally via peaty sand, diatomaceous muddy sand, and calcilutaceous muddy sand into the quartz sand and quartzo-calcareous sand of the basement margins, or wedges, sheets and tongues of quartz sand or quartzo-calcareous sand reworked from the margins may penetrate to a limited distance into the layers of the wetland fills. Where the sand bordering the margin of the wetland is reworked into shore-perpendicular to shore-oblique sand waves, the extension of the sand into the wetland sediments appears as a series of sand tongues or if bioturbated, muddy sand tongues penetrating into the wetland sediments. Where the basement materials directly interface with inner marginal facies, a complex mixture of sediment types are produced. Table 6 lists the range of marginal facies sediments produced in simple situations where end-member sediments of peat, diatomite and calcilutite directly interface with the basement materials.

Summary of intrabasin facies relations

For many wetland basins, the three facies, *i.e.,* central, basal, and marginal, often can be recognised. Table 7 summarises the facies types encountered in cross-basin stratigraphy for each of the main wetland biogenic sediment types with some typical examples. Specific intrabasin relations of central facies to the wetland margins and to the basal facies are illustrated in Figure 12.

In terrigenous sediment settings, where there is kaolinitic mud accumulating in the central basin, the basal facies is muddy sand, and the marginal facies is muddy sand and phytolithic muddy sand, as exemplified by Tangletoe Swamp and Lake Mungala.

Description of specific transects

A range of transects through wetland basins across and along the length of the Swan Coastal Plain are presented in Figures 10 and 11. These have been selected to illustrate a variety of basin settings for the sedimentary fill, a variety of vertical and lateral stratigraphic relationships, the symmetry or asymmetry of the ancestral wetland basin, and hence the symmetry/asymmetry of the wetland sedimentary lithotope, the variety of internally homogeneous or heterogeneous stratigraphic sequences, and the symmetry or asymmetry of facies across the basin. Annotated photographs of selected cores from specific depths and specific facies from these transects are illustrated in Figure 8.

The transects, in order from north to south are described as to their salient points below (Figures 10 and 11).

Transect A, at Lake Pinjar south, at the junction between Spearwood Dunes and Bassendean Dunes, is located across the central western part of a large shallow basin. The sedimentary sequence in this part of the basin consists of a thin diatomite overlying a moderately thick diatomaceous muddy sand, with an apron of quartz sand derived from the uplands to the west deposited on, and pinching out over the diatomite deposits to the east.

Transect B, at Melaleuca Park, within the Bassendean Dunes, is located across a small, moderately symmetrical basin, with a simple fill of peat overlying a transitional layer of peaty sand. The upper surface of the peat has

Table 7

Sediment types of the three facies of wetland basins

Central facies	Basal facies	Marginal facies	Typical examples
calcilutite	muddy (calcilutaceous) sand	carbonate intraclast sand/gravel; organic matter enriched calcilutite; muddy (calcilutaceous) sand; spongolitic/phytolithic muddy (calcilutaceous) sand	Lake Manning Lake Coogee Wetland 163, Becher Point
diatomite; organic-matter-enriched diatomite	muddy (diatomaceous) sand	diatomite intraclast sand/gravel; organic matter enriched diatomite; muddy (diatomaceous) sand	Lake Mariginiup Lake Jandabup Gnangara Lake North Lake
peat	peaty sand	peat intraclast sand/gravel; peaty sand	Karrinyup Road Swamp Lake Mealup Beenyup Swamp

been cracked, brecciated (Fig. 8), and fire-sculptured (*cf.* Semeniuk & Semeniuk 2005).

Transect C, also at Melaleuca Park, within the Bassendean Dunes, is located across a small, moderately symmetrical basin, with a simple fill of peat overlying a transitional layer of peaty sand. In this wetland, following a history of fire, the peat has been reduced to a diatomite (essentially a residual ash) that blankets the floor of the wetland.

Transect D, at Ellenbrook, is located across a small basin within the Pinjarra Plain. It is filled with fluvially delivered kaolinitic muddy sand.

Transect E, at Lake Jandabup, within the Bassendean Dunes, is located across a large irregularly shaped basin floor, with asymmetry in thickness of sedimentary fill. Diatomite dominates the western part of the basin, and pinches out eastwards. The eastern part of the wetland is sand-floored, and its shore is comprised of a large beachridge system that has developed by wave and wind reworking of the sand exposed along the basin floor. Diatomite also occurs in the inter-beachridge swale east of the main basin.

Transect F, at Beenyup Swamp, within the Spearwood Dunes, is located across a large broadly symmetric basin filled generally with a simple sequence of peat formed asymmetrically from east to west, with simple relationship to the underlying and lateral sand. The surface lithologies of the deposit are fibrous peat, interlayered fibrous peat and local lenses of diatomaceous peat, and brecciated peat (Fig. 8). At depth, within the root-structured and fibrous peat, there are charcoal horizons (Fig. 8).

Transect G, at Little Carine Swamp, within the Spearwood Dunes, is located across a small slightly asymmetric basin filled with a complex sequence of a basal peat and an upper (shelly) calcilutite, with an inter-digitating relationship between the wetland fill and its margins. Peaty sand underlies the basal peat unit, and forms tongues that extend from the sandy margins of the wetland to a limited extent towards the basin centre.

Transect H, at Lake Gwelup, within the Spearwood Dunes, is located across a large asymmetric ancestral basin, with a highly irregular floor, filled with a complex sequence mainly of peat and calcilutite. There is an intrabasinal facies change with peat dominated sequences to the east in the shallow parts of the ancestral basin, and calcilutite dominated sequences to the east in the deeper parts of the ancestral basin. The margins of the wetland, under the influence of vegetation and its detritus, is dominated lithologically by organic matter enriched sediments. The upper layer of the calcilutite-filled eastern basin is organic matter enriched calcilutite (with scattered shell), that has sharp to gradational contact with underlying calcilutite (Fig. 8). The central basin sediments have a gradational facies relationship between the wetland fill and its margins, grading into organic matter enriched calcilutite, and then into peaty sand. Locally, in the lower part of the peat-dominated eastern part of the basin, there is lithological variation, with diatomaceous muddy sand forming the lowest unit in the sequence, underlying peaty sand (Fig. 8); this sequence is a facies variant outside the E-W transect illustrated in Figure 10).

Transect I, at Karrinyup Road Swamp, within the Spearwood Dunes, is located across a large asymmetric basin filled dominantly with peat. Within the peat sequence, fibrous, massive, root-structured, and laminated peat can be distinguished. There is a lens of thin diatomite (showing "seat earth") at depth, which pinches out to the east and to the west. Within the horizon of the diatomite, there is a small unit of diatomaceous peat. The lateral relationships of the main body of peat, along the edge of the basin, are gradational into sand, via peaty sand, or inter-digitating with sand tongues extending out into the wetland basin. The floor of the basin is generally peat directly overlying quartz sand with incipient development of thin peaty sand.

Transect J, at Kenwick Swamp within the Pinjarra Plain, shows basins filled with fluvially delivered interlayered and laminated mud, sand and muddy sand. A ferricrete sheet locally underlies the Holocene wetland sediments, and extends discontinuously under the Pleistocene sediments at the level of the water table.

Transects K, at Brixton Swamp within the Pinjarra Plain, is located across a small basin naturally excavated into Pleistocene sediments. The natural excavation has removed the surficial sand to expose underlying muddy sediments, which form the floor of the basin. The excavation has a veneer of kaolinitic mud.

Transect L at Lake Manning, in the Spearwood Dunes, is located across a large, deep, somewhat symmetrical basin, largely filled with grey to cream, laminated calcilutite, with lamination locally punctured by burrow structures (Fig. 8). In detail, the calcilutite sequence in the central basin also exhibits thin, laminated layers (1–2 cm thick) of organic matter enriched calcilutite and organic matter layers that extend across the basin. The margins of the basin, which appear to have been inhabited in the long term by peripheral vegetation, wherein the marginal facies has been generated, are underlain by organic matter enriched calcilutite, and locally peat; these organic matter rich sediments are consistently present in the stratigraphic profile as a marginal facies and not in the central facies. The base of the sequence is muddy sand (calcilutaceous muddy sand, or locally, diatomaceous muddy sand; Fig. 8) in the central basin or calcilutaceous muddy sand and peaty sand towards the basal margins of the basin.

Transect M, at Little Rush Lake, in the Spearwood Dunes, is located across a relatively small basin with an irregular floor. It is filled by peat. The eastern margin and the basal contact is peaty sand, gradational between peat and the underlying sand. The western margin has tongues of sand extending into and interlayered with the peat.

Transects N and O, across both un-named basins near Folly Pool, on the Pinjarra Plain, are located across small basins filled with fluvially derived sand and kaolinitic mud, respectively. The sand-filled basin appears to be an abandoned fluvial channel, now acting as a sediment trap reservoir.

Transect P, at Point Becher wetland 162 (C A Semeniuk 2006), within the Quindalup Dunes, is located across a small wetland showing a symmetrical basin floor shape, and gradual fill of the basin by infiltration of carbonate mud into the underlying sand (of the Safety

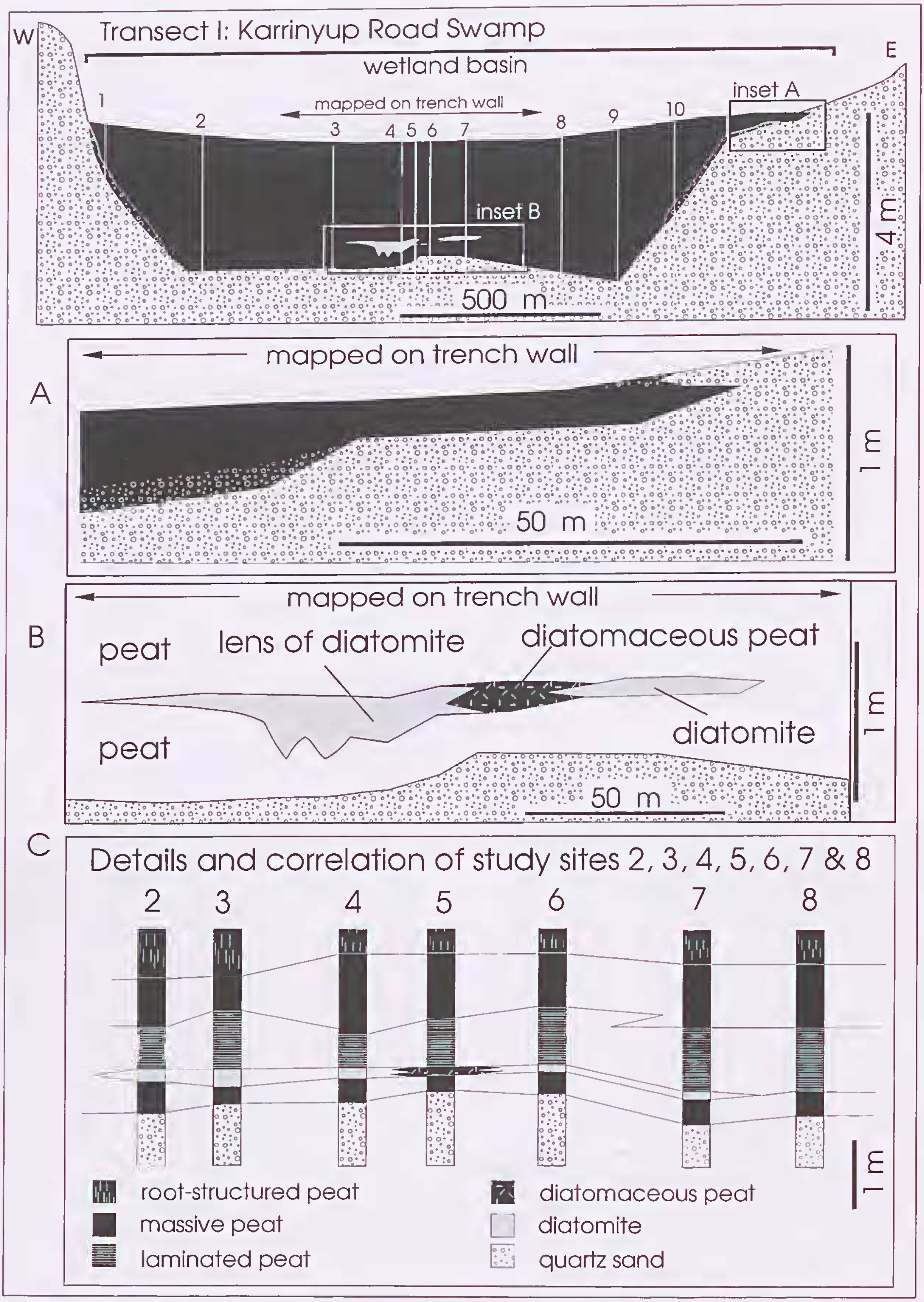


Figure 11. Transect I, Karrinyup Road Swamp, showing stratigraphy. Inset A: Detail of marginal stratigraphy and, on adjoining page, photographs A-D of cores from sites along the margin. Inset B: Diatomite interlayered with peat and, on adjoining page, photographs E–H of peat and contact of diatomite with peat (sharp lower contact, and root-structured upper contact, similar to "seat earth" where coal seams overlie clay or sand, *cf.*, Holmes 1965; Bates & Jackson 1987); lens cap in F is 50 mm diameter. Inset C: Stratigraphic correlation of sites 2-8.

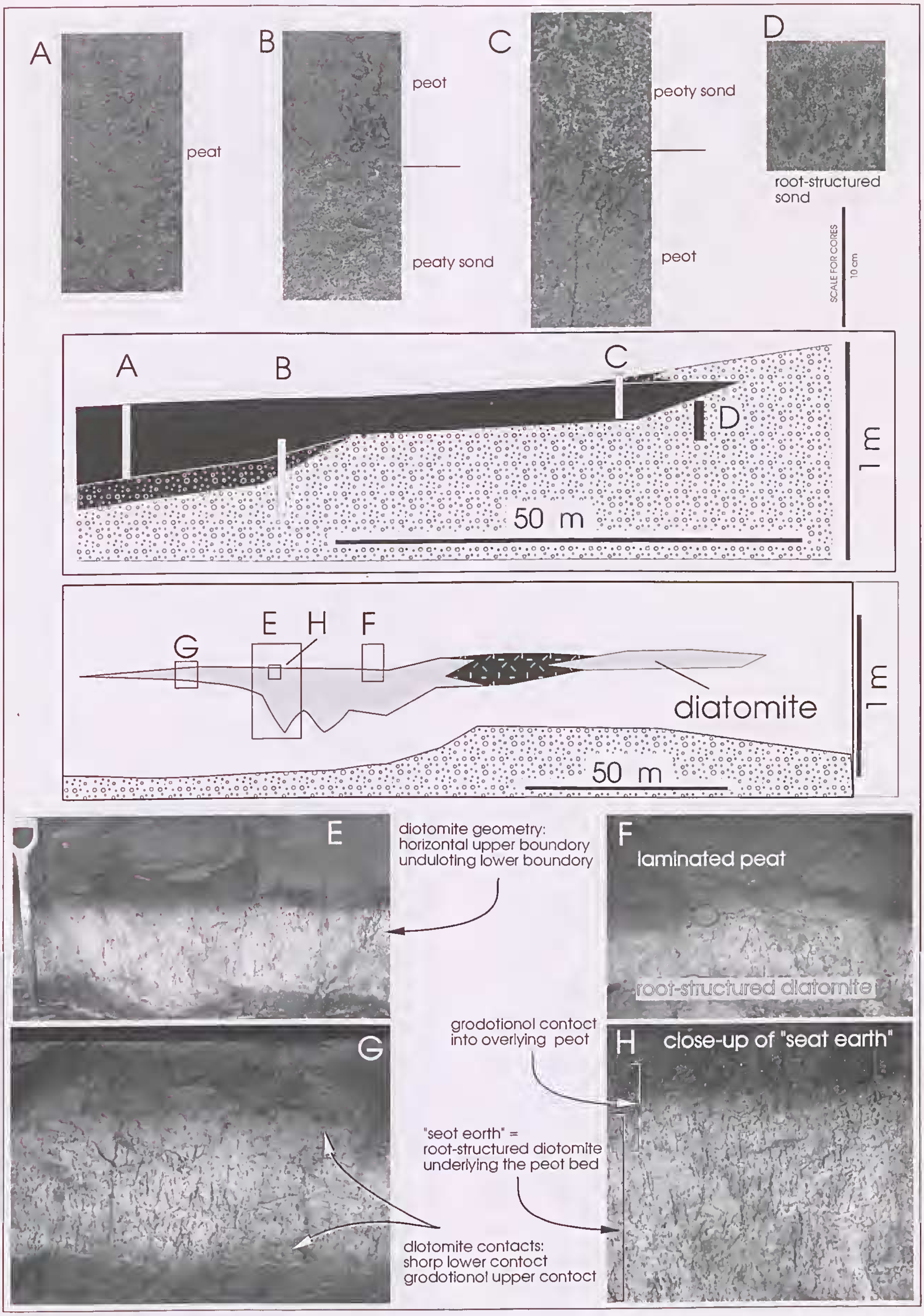


Figure 11 (cont.)

Bay Sand) to form calcilutaceous muddy sand, by calcilutite, and then by peat. Over its history, due to hydrochemical and geochemical changes, the floor of the basin has subsided (C A Semeniuk 2006).

Transect Q, at Point Becher wetland 163 (C A Semeniuk 2006), within the Quindalup Dunes, is located across a small wetland showing a symmetrical basin floor shape, and gradual fill of the basin by infiltration of carbonate mud into the underlying sand (of the Safety Bay Sand) to form calcilutaceous muddy sand. The margins of the wetland show that there have been sand incursions into the wetland, resulting in tongues of sand extending over and burying the edge of earlier wetland deposits. The base of the wetland shows that it too had a complex history, with a two-staged development of initiation of wetland conditions. Over its history, due to hydrochemical and geochemical changes, the floor of the basin has subsided (C A Semeniuk 2006).

Transect R, at Point Becher wetland Wawa (C A Semeniuk 2006), within the Quindalup Dunes, is located across a small wetland also showing a symmetrical basin floor shape. It shows a gradual fill of the basin by infiltration of carbonate mud into the underlying sand (of the Safety Bay Sand) to form calcilutaceous muddy sand, followed by organic matter enriched calcilutite, and finally a capping of peat. The floor of the basin, due to hydrochemical and geochemical changes, has subsided (C A Semeniuk 2006).

Transect S, at Point Becher wetland sw-ii (C A Semeniuk 2006), within the Quindalup Dunes, is located across a small and young wetland showing a symmetrical basin floor shape, and gradual fill of the basin by infiltration of carbonate mud into the underlying sand (of the Safety Bay Sand) to form calcilutaceous muddy sand.

Transect T, at Lake Mealup, located across in a wetland occurring at the junction between Spearwood Dunes, Bassendean Dunes and Pinjarra Plain, illustrates a complex setting for a wetland basin. The basin floor is largely asymmetrical. To the east, it is underlain by muddy sediments of the Guildford Formation (that underlie the Pinjarra Plain); to the north and northeast, it is underlain by quartz sand (Bassendean Sand of the Bassendean Dunes), and to the west it is underlain by quartz sand and limestone of the Spearwood Dunes. As a result, the basin floor, *i.e.*, the Pleistocene/Holocene unconformity, is underlain by muddy sand to the east, and quartz sand to the west. The basin has been filled in two stages: the lower part of the basin depression itself to the east consists of kaolinitic mud; peat, however, constitutes the main sedimentary fill in the basin, dominating the western part. The peat sequence consists of root-structured, bioturbated, fibrous peat to brecciated peat in the upper layers, and root-structured, bioturbated fibrous peat to laminated peat in lower layers (Fig. 8). Locally, at about a depth of 1 m, there is a thin lens of diatomaceous peat. The peat has a gradational (peaty sand) contact with any underlying sand, and a sharp contact with the kaolinitic mud. The upper eastern shore is marked by a shoe-string deposit of sand, which also is part of the wetland complex. This sand body is a beachridge accumulation that lies on muddy sand of the Guildford Formation, and is onlapped by the peat deposits of the central basin. The western shore, in a gradient towards the high water mark, is underlain by peaty sand, organic matter enriched sand, and sand.

Transect U, at Willie Pool, in the Bassendean Dunes, is located across a small basin, with asymmetric ancestral shape. It is filled with peat (and some diatomaceous peat), that has gradational contact (peaty sand) laterally and basally with the underlying Bassendean Sand. The western accumulation of peat is thicker than the eastern part, and extends higher in the profile in relation to the high water level.

Transect V, at Crampton Swamp, in the Bassendean Dunes, is located across a small basin, with symmetric basin floor shape. It is filled with thin peat that has gradational contact (peaty sand) laterally and basally with the underlying Bassendean Sand.

Geographic distribution of stratigraphic types in wetlands

As with composition of surface sediments, the stratigraphy of the wetland fills varies according to geologic and geomorphic setting, climate, and host water chemistry. Hence, there is a pattern of stratigraphic sequences in an east-west transect, and from south to north on the Swan Coastal Plain. The east-to-west distribution can be related to consanguineous suites, and the south-north distribution is related to consanguineous suites and to climate. A summary of the east-west pattern of sedimentary fills in wetlands in relation to consanguineous setting in the central part of the Swan Coastal Plain is presented in Table 8.

Table 8

Dominant autochthonous sedimentary sequences in key consanguineous wetland suites, central Swan Coastal Plain.

Consanguineous wetland suite	Dominant stratigraphic sequence
Becher	calcilutite
Peelhurst	calcilutite, organic matter enriched calcilutite
Cooloongup	calcilutite
Yanchep	calcilutite, peat
Stakehill	calcilutite, peat
Coogee	calcilutite
Balcatta	peat, calcilutite
Bibra	diatomite
Pinjar	diatomite
Gnangara	diatomite, peat
Jandakot	peat, diatomite
Riverdale	peat, diatomaceous peat
Bennett Brook	peat, kaolinitic mud, muddy sand
Mungala	kaolinitic mud, muddy sand

Key processes in wetlands to develop sediments, structures, diagenetic products, and stratigraphic contacts and sequences

There is a range of processes that occurs within wetlands that generates distinctive sedimentary products in terms of sedimentary particles, sediment types, sedimentary structures, and diagenesis, and various stratigraphic contacts and sequences. While details of these processes and products, for use as a template to interpret Holocene wetland stratigraphy, will be the subject of a later paper, a brief description of some of the key processes and products is provided here as they have a bearing on understanding the origin and significance of wetland sediments and stratal types described in this paper, as will be dealt with later in the Discussion and Conclusions. These processes often are location-specific, *i.e.*, they occur in definite environments in relation to the wetland centre or margins, or are associated with specific biotic zones. In addition to intrabasinal processes, there are regional factors, such as climate fluctuations and/or unidirectional climate changes during the Holocene, or groundwater chemistry changes that may play a part in influencing wetland stratigraphy and causing changes or alternations in lithology.

The key processes occurring within wetlands are: 1. biogenic sediment production; 2. infiltration; 3. bioturbation; 4. *in situ* vegetation accumulation; 5. organic matter contribution; 6. sponge spicule accumulation; 7. phytolith accumulation; 8. margin of wetland sedimentation and shoreward transport; 9. deep water accumulation; 10. desiccation; 11. pyrogenesis; 12. winnowing; 13. delivery of fluvial mud and sand; and 14. alternating hydrochemistry. They are described in Table 9 in relation to their products, and location within a wetland.

The issue of hydrochemical changes is discussed in more detail here because it is a significant one that relates to interpreting sedimentary sequences. It is important to recognise that lithologic changes and lithologic alternations may be due to: 1. regional factors such as a changing climate (*e.g.*, a general change in climate from relatively arid to relatively more humid, as driven perhaps by Earth-axis precession; see Semeniuk 1995), and manifest, for example, by a change in gross stratigraphy from calcilutite to peat, or a change in stratigraphy from calcilutite to organic matter enriched calcilutite, 2. a fluctuating climate (*e.g.*, a 250-year cycle; see Semeniuk 1995), resulting in finely interlayered calcilutite and peat, or finely interlayered calcilutite and organic matter enriched calcilutite, or 3. hydrochemical changes in the wetland basin (see C A Semeniuk 2006). In the Becher area, C A Semeniuk (2006) determined that many of the vegetation changes within a wetland basin were due to intrabasinal hydrochemical evolution as related to vegetation influencing salinity of the shallow groundwater, which, in turn, resulted in changes in vegetation. In that context, in the Becher area, a range of different basins with variable hydrochemical history showed a varying vegetation history that reflected intrabasin factors and not regional climatic factors – such vegetation changes can translate to a varying lithology in their contribution to sediment (to form peat), and/or modification of sediment to form organic matter enriched calcilutite. As such, it is important to be able to distinguish lithological changes generated by hydrochemical evolution or fluctuations, from those induced from unidirectional climate change, or climate fluctuations.

Synthesis, discussion and conclusions

This synthesis and discussion focuses on eight features of wetland sedimentology, and stratigraphy, and their implications for understanding hydrology, ecology and management: 1. the variability of sediment thickness in a wetland basin; 2. the nature of the basal facies; 3. the range of primary sediment types across the Swan Coastal Plain related to setting; 4. the lateral facies variation in stratigraphy within a wetland basin; 5. homogenous *versus* heterogeneous stratigraphic sequences; 6. stratigraphy as a measure of hydrochemical and biotic stability, and hence palaeo-environmental history; 7. the asymmetry of stratigraphy; 8. the significance of stratigraphy to hydrology; and 9. the significance of stratigraphy to plant ecology.

The variability of thickness of the various sediment types and total thickness of the basin sediment fill is related to the factors of availability of a given sediment type, the depth of original basin floors with respect to the final late Holocene regional water table, and sedimentation rates. For instance, low rates of influx of clay within a clay-poor setting would result in thin clay beds accumulating in a basin. But given adequate rates of sedimentation, the thickness of basin fill will depend on the depth of an original wetland basin floor at the time of inundation, when, with post-glacial rising sea levels, the water table rose to intersect the palaeo-land surface generally some 10,000–8,000 years BP. Local topographic depressions that were deep enough to be inundated early by a rising water table (sympathetically rising with sea level at the ending of the last ice age some 20,000 years ago) would have commenced sedimentation earlier, and would have developed the thickest sequences. Sediments would continue to fill a basin until the floor was built up to the highest water of the current regional water table level. Thereafter, wetland sedimentation processes largely would have ceased. Most of the wetlands basins encountered in this study had relatively shallow deposits of sediments, indicating that the floor of the original depressions (that were to become the floor of the wetland basin) were located more or less within the position of the present regional groundwater level. Some of the large lakes and wetlands, such as North Lake, Lake Manning, and Karrinyup Swamp, have several metres of sedimentary fill, indicating that they were relatively deep depressions at the time of the early Holocene, and were inundated early with the rising regional water tables at the end of the Pleistocene. On the other hand, other large lakes and wetlands such as Lake Mariginiup, Lake Jandabup, and Lake Pinjar, have relatively thin sedimentary fills, indicating that their ancestral floors were located near the position of the present regional water table. However, full exploration of this matter is beyond the scope of this paper, and will be investigated further, in combination with radiometric dating of wetland sequences, in a later paper (Semeniuk & Semeniuk, 2006, unpublished manuscript).

In Swan Coastal Plain wetland basins that are filled with fine grained sediment (either biogenic sediment or terrigenous sediment), the base of the sedimentary fill generally is a muddy sand basal sheet. This muddy sand sheet effectively signals the commencement of wetland sedimentation. As described by Semeniuk & Semeniuk (2004), processes of vadose infiltration and bioturbation combine to deliver fine grained wetland sediment into any underlying basement sand (the original ancestral floor of the wetland basin). The thickness of the basal muddy sand sheet varies, and would have depended on

Table 9

Processes, description and products, and location within wetlands

Process	Description and products	Location within wetland
biogenic sediment production	production of biogenic material by macrophytes, filamentous and unicellular algae, diatoms, and invertebrate fauna leading to the development of peat, diatomite, and calcilutite, and shell beds	depending on depth of water, and frequency of inundation, these biota and their products may be basin wide, or restricted to the margins of wetlands
infiltration	fine grained sediment infiltrating, by vadose processes, into underlying basement sand	along the base in the early stages of basin filling, and along the margins during later stages
bioturbation	fine grained sediment bioturbated by vegetation and fauna into underlying basement sand, and mixing and perturbation of any interlayered and laminated sediment; in modern environments, depending on the biota, bioturbation is most intense in the upper 10–20 cm of the sediment, but can be effective to 30–50 cm	basin-wide, but most common along the margins
in situ vegetation accumulation	accumulation of macrophyte plant material and its detritus where it is growing, resulting in the formation of fibrous to massive peat beds, or (in conjunction with degradation and bioturbation) organic matter enriched sediments	basin-wide in shallow water wetlands; restricted to margins in deeper water wetlands or where there is consistent peripheral vegetation
organic matter contribution	accumulation of macrophyte plant material and its detritus along margin, or transported into deeper water, to form organic matter enriched sediment, or deeper water peats	basin wide, or restricted to margins in deeper water wetlands or where there is consistent peripheral vegetation
sponge spicule accumulation	accumulation of freshwater sponge spicules after the death of the sponges, or after combustion of the supporting vegetation into sediments forming spongolitic peat and spongolitic diatomite	if sponges are restricted to peripheral vegetation, spicule accumulation is largely circumferential to the basin; in shallow water wetlands wholly covered by vegetation, spicule occurrence is basin-wide
phytolith accumulation	sedge assemblages upon their death and decay, or combustion in a fire, yield phytoliths and contribute particles to the sediments	if sedges are peripheral to a wetland, accumulation is largely circumferential to the basin; in shallow wetlands wholly covered by vegetation, phytolith contribution is basin-wide
margin of wetland sedimentation and shoreward transport	various processes result in preferential deposition of sediments in margin zones; these include transport by wave and currents of fine grained sediment via suspension to the wetland margin and its accumulation there (usually amongst peripheral vegetation); and wave transport of sand by traction to shorewards	margin of wetland
deep water accumulation	accumulation of fine grained matter, such as carbonate mud, plant detritus, diatoms, unicellular algae, carried in suspension and settling in deep water	deep water parts of wetland
desiccation	drying out and cracking of sediments to form gravel and sand intraclasts of peat, diatomite and calcilutite	largely confined to margins, though for shallow water wetlands; this can be basin-wide (*e.g.*, peat breccia can form a surface basin-wide horizon)
pyrogenesis	combustion by fire consumes peats, and can generate organic-matter-free lithologies such as diatomite; by cracking sediments generates intraclasts; forms sand lenses and ash deposits (Semeniuk & Semeniuk 2005)	largely confined to margins, though for shallow water wetlands; this can be basin-wide (*e.g.*, peat breccia generated by fire can form a surface basin-wide horizon)
winnowing	wave action and currents winnow sandy and gravelly muddy sediments to leave coarse lags such as shell beds, and intraclast deposits	largely confined to margins, though for shallow water wetlands; this can be basin-wide
delivery of fluvial mud and sand	floods carry kaolinitic mud in suspension and quartz sand by traction to basins on the Pinjarra Plain, progressively filling them with these sediments	fluvial delivery of terrigenous sediments fills the interior of the wetland basins
alternating hydrochemistry (see below)	an alternation of hydrochemistry driven by alternating vegetation succession changes the composition of the flora and fauna, leading to an alternation of processes (described above) and to alternation of lithology	this process can be restricted to the wetland margins; depending on the depth of a wetland, it can also be basin-wide

the organisms involved in the bioturbation. Shallow rooted plants effect bioturbation to depths of 10–20 cm; trees effect bioturbation to depths more or less of 40 cm; foraging mammals effect bioturbation to depths of 10–15 cm; burrowing crustaceans dig burrows as deep as 50 cm; and insects and other invertebrates burrow to depths of 5–30 cm. The effect is that fine grained sediment, delivered by fluvial processes, or generated biogenically in the basin, is bioturbated into the underlying basement sand to form a muddy sand sheet (*viz.*, kaolinitic muddy sand, peaty sand, diatomaceous muddy sand, and calcilutaceous muddy sand).

The range of primary sediment types across the Swan Coastal Plain appears related to geologic/geomorphic setting and its attendant hydrochemistry. At one extreme, fluvially dominated systems of the Pinjarra Plain are dominated by kaolinitic clay and fluvial sand as wetland basin fills, and there is an absence of such terrigenous sediments in the dune-dominated landscapes of the Quindalup Dunes and Spearwood Dunes. Similarly there is an absence of such terrigenous sediments in the dune-dominated landscapes of the Bassendean Dunes, though there is terrigenous clay in the fluvially over-printed landscape of the Bassendean Dunes in wetland settings such as the Bennett Brook Suite (C A Semeniuk 1988). Carbonate sediments dominate wetlands located in carbonate terrains of the Quindalup Dunes and Spearwood Dunes, implicating the geochemical (carbonate) foundations of the wetlands as the hydrochemical source that drives these systems. Where macrophytic vegetation and diatom populations have been sufficiently productive, wetlands set in carbonate terrains may develop peat and diatomaceous peat, but often such wetlands have a stratigraphy that indicates alternating calcilutite-dominated and peat-dominated sedimentation. Diatomite and peat dominate the wetlands located in the quartz sand rich terrain of the Bassendean Dunes, and carbonate mud production is not (and was not) a feature of these carbonate-poor terrains. Where peat production by macrophytes was relatively low, diatomites dominate, and where peat was formed, peat and diatomaceous peat were developed.

While there is a change in sediment composition across the Swan Coastal Plain in relation to geology/geomorphology and hydrochemistry, there are also lateral facies variations in stratigraphy within wetland basins. In the first instance, the sediment facies variation can be related to the physico-chemical and biological gradients that occur from the central basin to the margin of the basin. That is, permanently inundated, or otherwise deeper parts of the wetland basin, with a more consistent aquatic or water-saturated environment, will grade to the margin environments where physico-chemical processes, such as wave action, desiccation, chemical precipitation, amongst others, as described earlier, that are specific to wetland margins, combine to create distinctive sedimentary products. Wetland margins are also zones where there may be biota assemblages contributing organic matter to the sediment, or contributing sponges spicules and phytoliths to the sediment, and where wetland sediment fill interfaces with the basement materials. A summary of the idealised lithological nature and stratigraphy of wetland basins in terms of basal facies, marginal facies, and central facies for diatom-dominated, calcilutite-dominated, and peat dominated basins, is shown in Figure 12.

However, in addition, there are also facies changes in wetland basins *within* the central facies. For instance, at Lake Gwelup, for the equivalent thickness of several metres of its sedimentary fill, the basin is dominated by peat in its eastern part, and dominated by peat overlying calcilutite in its western part. Karrinyup Road Swamp shows a particularly interesting lithologic change in the central facies: a lens of diatomite, some 50 cm thick, passes laterally into diatomaceous peat and then to peat over some tens of metres. On the other hand, a large number of large wetland basins show little variation in lithology within the central basin, *e.g.*, the calcilutite of Lake Manning, the diatomite of Lake Pinjar, and the peats of Beenyup Swamp, Willie Pool and Lake Mealup. Lateral lithologic homogeneity is particularly the case for small basins. For example, apart from the marginal and basal facies, the central basin lithology of wetlands in the Becher Suite is dominated by calcilutite, and small basins in the Jandakot Suite and Riverdale Suite in the Bassendean Dunes are dominated by peat and diatomite, and peat, respectively.

One of the most interesting aspects of the vertical sedimentary fill of the wetlands is whether their central facies is stratigraphically homogenous or heterogeneous. The wetlands of the Becher Suite (calcilutite-filled), those in the Coogee Suite (calcilutite-filled), certain basins in the Yanchep Suite (*e.g.*, Waluburnup Swamp which is peat-filled), and many of the wetlands of the Jandakot Suite, Riverdale Suite, and Gnangara Suite (peat or diatomite filled) display relatively homogeneous stratigraphy vertically. In contrast, wetlands either located in the Spearwood Dunes or at the interface between the Spearwood and Bassendean Dunes may exhibit vertical stratigraphic heterogeneity: for example, Lake Joondalup, Little Carine Swamp, Balcatta Swamp, Leda Swamp, The Spectacles, and Bollard Bullrush Swamp.

In a geohistorical sense, over the period of the Holocene, the vertical homogeneity or heterogeneity of wetland stratigraphy is an important issue. It can be used as a measure of hydrochemical stability and hence biotic stability. For example, if it is accepted that hydrochemical and hydrological patterns regulate biotic response, then the consistent occurrence of calcilutite (generated by breakdown of charophytes; *cf.* Semeniuk & Semeniuk 2004) over, say, 5000 years of stratigraphic record, signals an environment relatively hydrochemically and hydrologically stable. Wetlands wholly and consistently filled with peat derived from, say, *Baumea articulata*, similarly signal relative hydrologic and hydrochemical stability over the period of peat accumulation. On the other hand, wetlands that are filled with sequences that change from peat to diatomite to calcilutite, or that alternate between lithologies, signal changes in the hydrochemical environment within the wetland. This is a particularly important matter to note when at the same time, over the same period of the Holocene, wetlands elsewhere are not exhibiting such dynamics, and thus it provides an insight from a stratigraphic perspective of the long-term (natural) comparative hydrologic, hydrochemical and biological stability of individual wetlands. Information on these stratigraphic signatures

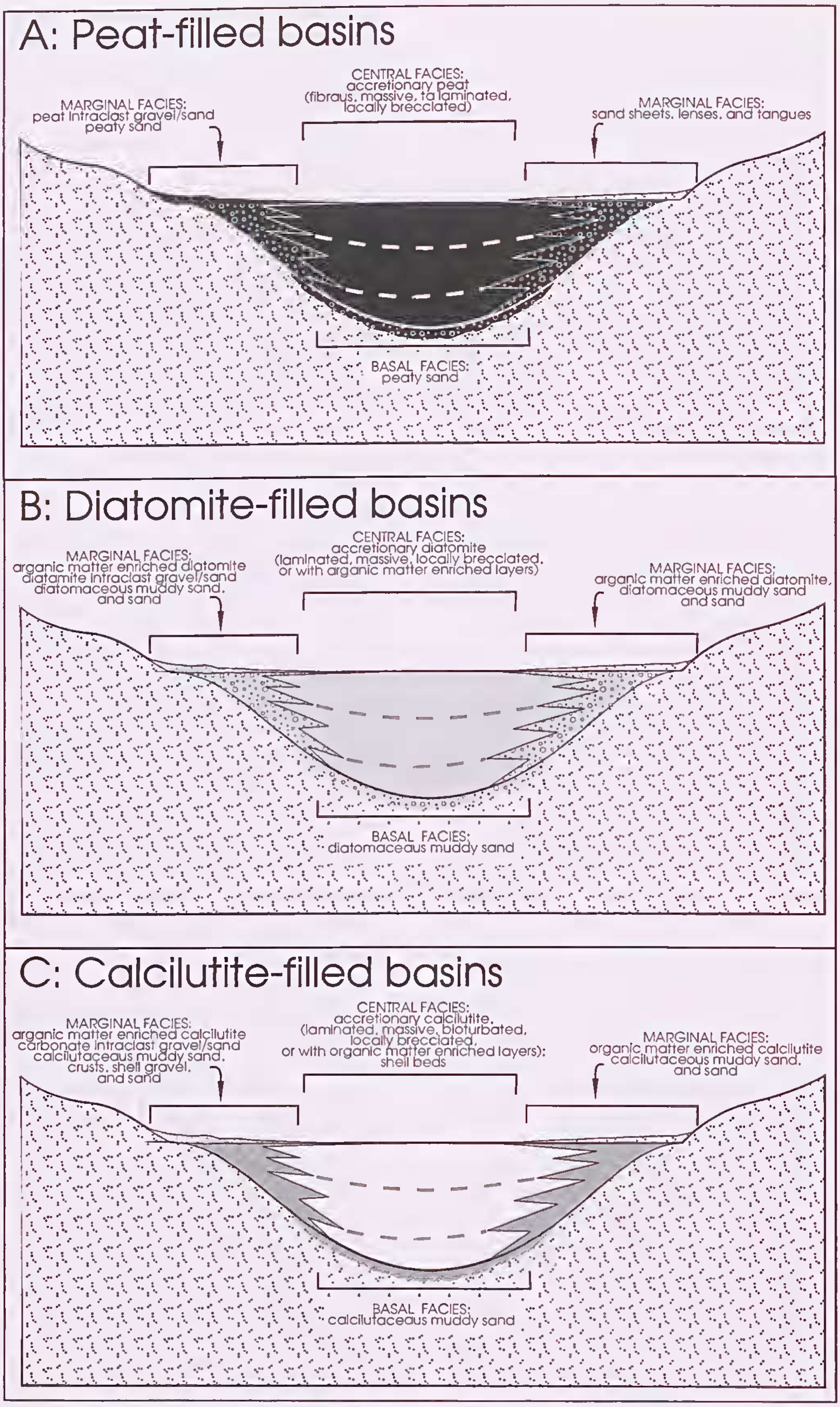


Figure 12. Summary annotated diagram showing idealised lithological nature of the basal facies, central basin facies, and marginal facies for peat-filled, diatomite-filled, and calcilutite-filled basins, and their stratigraphic relationships. Because of the complexity and variety of sediments that are formed in the marginal facies, the left hand side of the marginal facies of each of the basin sedimentary fills highlights only those lithologies formed specific to the inner marginal facies (with sources of sediments mainly from the central basin), while the right hand side of the marginal facies highlights sediments produced by as a result of incursions of sand into the basin (with sediment reworked or shed mainly from basin margins, *i.e.*, extrabasinal), without implication that there is consistently such asymmetry within the basins. The emphasis in this diagram is on intrabasinally derived biogenic sediments systems.

of long-term and medium-term wetland ecosystem stability has important implications for understanding wetland management.

The alternations in lithology within wetland basins, and how it is interpreted have palaeo-environmental implications. It is necessary to separate those alternations due to climate changes, from those induced by alternating hydrochemical changes or unidirectional hydrochemical evolution of wetlands, from those induced by ecological processes (linked to hydrochemical changes). Sediments within wetland basins are autochthonous (*i.e.*, formed intrabasinally), and therefore provide a more reliable indicator to separate hydrochemical and ecological changes from climatic changes. To date, climate changes have been inferred from mainly extrabasinally derived pollen rain. Future research could be directed to the study of palaeo-hydrochemistry, and hydrochemical history, as reflected in wetland sediment through their fossil biota.

Stratigraphy has another important role to play in wetland management, *viz.*, in the arena of wetland hydrology, and plant ecology. For the Swan Coastal Plain, Townley *et al.* (1993) provide a series of hydrological models of groundwater flow through wetlands (specifically lakes), for unconfined aquifers, but deal with large-scale hydrological processes, identifying perched lakes, groundwater recharge lakes, groundwater discharge lakes, and groundwater throughflow lakes. One of the important factors in the treatment of groundwater interactions with wetlands is the local effect of wetland sediments on groundwater flow (*i.e.*, wetland sediment thickness, their geometry, transmissivity, and nature of contact with the surrounding terrain), as this will perturbate groundwater patterns at the local scale, the scale at which groundwater enters a wetland and the scale at which peripheral vegetation responds to hydrological processes. As a consequence, the small-scale stratigraphic relationship along wetland margins becomes important, as this will influence small-scale hydrologic processes, and depending on lithology, hydrochemical products along the wetland margin. C A Semeniuk (2006) emphasised this factor in the study of hydrology around the individual wetland basins in the Becher Suite. The Becher wetlands are a rain-fed recharge system that translates to a regional throughflow system. Depending on the thickness and complexity of the sedimentary fill of these wetland basins, there are perturbations at the local scale to the regional throughflow pattern, culminating in variable degrees of local diversion of flow in the various wetlands, and in places, upwelling (C A Semeniuk 2006). In addition, in the Becher wetlands, how water is delivered to a wetland from up-slope sources often depends on the stratigraphic nature of the wetland margins, *i.e.*, whether there are sheets and tongues of sand that penetrate into the wetland sediment sequence.

In this context, from a stratigraphic perspective, we suggest that the small-scale stratigraphic relationships along the base and margins of the wetlands, and the nature of stratigraphic layering (resulting in variable transmissivity) should be significant factors to consider in determining how regional groundwater enters into, percolates through, and discharges from a wetland basin. This will be a small scale hydrological feature critical to management of wetland hydrology if wetlands are to be environmentally sustained or managed rigorously.

At medium and large scales, stratigraphy, in conjunction with hydrology as outlined above, also has a role to play in plant ecology. The variety of stratigraphic contacts, in terms of geometry and lithology, and their associated hydrological and hydrochemical processes will influence plant associations along the margins of wetlands. To date, there has been a tendency only to examine the surface material (what authors generally term the "soils"), but we suggest that stratigraphy is a factor that needs to be addressed to understand the distribution and maintenance of plant associations, particularly at the finer scales, in any phytoecological study of wetlands.

Also, at the large scale, asymmetry in stratigraphy needs to be addressed in holistic environmental studies. This asymmetry may be due to: variable biogenic production rates across a wetland basin; variable transport mechanisms and sink sites across a basin; an irregular ancestral basin shape; variable hydrological factors in response to regional groundwater table gradients; or a variable cross-basin fire history. Asymmetry in stratigraphy can lead to asymmetry in hydrological function, in geochemistry, and hydrochemistry, and hence in biota. The result stratigraphically will be expressed as variation in lithology across a basin, and/or variation in sediment thickness across the basin, and variation to the extent that sediments occur above the mean high water datum. This large-scale pattern of stratigraphic asymmetry underlying wetlands has not been adequately addressed in the analyses of the phytoecology or macroinvertebrate ecology of wetlands, and we suggest it is an underlying determinative factor in the larger scale ecological functioning of wetlands, and hence in the proper management of wetlands. Also, any asymmetric stratigraphic pattern may have an interactive feedback relationship with vegetation. That is, the asymmetry in stratigraphy across a basin may alter the hydrologic functioning and processes across a wetland to the extent that vegetation and other biota respond in terms of the types of assemblages that may inhabit the wetland margins, or in their rates of primary or secondary production, which in turn results in a contrast in sediment accumulation rates, hence further amplifying the asymmetry in sediment thickness, or amplifying the contrast in facies.

From the results of this paper, we emphasise that to fully investigate wetland stratigraphy, with all that is recorded sedimentologically, biologically, and diagenetically, and to fully interpret the stratigraphic sequence lithologically, there is a need, firstly, to place sedimentary sequences in a geologic, geomorphic and hydrochemical context, and secondly, to construct across-basin stratigraphic relationships for a given wetland basin. Such an approach, as mentioned in the Introduction, places palaeobiological sequences and a single-core lithological sequence for large wetland basins in a context. It provides a more comprehensive database for reconstruction of wetland palaeo-sedimentology and history, provides a framework for hydrologic processes and functions, and provides a framework for determining and understanding ecological processes, ecology patterning (*e.g.*, zonation), and biodiversity. We suggest also that the stratigraphic approach adopted in this paper should form the foundation for unravelling the sedimentological, hydrologic, hydrochemical, climatic and biologic history of the wetlands across the Swan Coastal Plain, and for understanding current wetland hydrology and wetland vegetation ecology.

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